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The residual liquids of crystallizing magmas.

By Clarence N. Fenner
Geophysical Laboratory, Carnegie Institution of Washington.

[Read March 17, 1931; communicated by the General Secretary.]

In the Mineralogical Magazine for September, 1930, Dr. Frederick Walker describes 'A tholeiitic phase of the quartz-dolerite magma of central Scotland'. Several pages of the article are devoted to a consideration of the phenomena he has observed in these rocks in their bearing upon certain views which I have expressed. In most respects Dr. Walker has clearly grasped the essential features of my thesis, and his efforts to obtain further information on the various points have been well directed. I am glad to welcome such a discussion as he has given, even though his conclusions are somewhat opposed to mine. In one respect, however, he has apparently overlooked an essential feature of my argument. On this matter, and on some points of evidence given, I should like to present some discussion. I desire also to examine certain other recent papers by Daly and Barth and by Bowen, Schairer, and Willems, in which the views expressed in my article have met with some criticism.

In the article[1] to which Dr. Walker refers I have examined the course of crystallization of basalts with reference to the theory that all other igneous rocks have been derived from basaltic magmas

[1] C. N. Fenner, The crystallization of basalts. Amer. Journ. Sci., 1929, ser. 5, vol. 18, pp. 225–253 [Min. Abstr., vol. 4, p. 507].

by processes which involve a separation, at different stages, of crystalline minerals from residual liquids, and that the differences in chemical composition exhibited depend solely upon the differences between crystalline aggregates and the liquids in which they are formed. This is a view which is now accepted by probably a majority of petrologists, and is of fundamental importance in petrogenic theory. While I have recognized that such a process should be of great importance, and I should consider it a major factor in many occurrences where basic intrusives have separated into a highly olivinic lower portion and a relatively olivine-free upper portion, I have observed many phenomena, especially in field work but also in laboratory investigations, which seem inconsistent with the view that this process alone is able to meet, or, in nature, has met all the requirements of the phenomena of differentiation.

In the article on the crystallization of basalts the argument is that in order to determine if crystallization is the all-important factor in petrogenesis that it is assumed to be, it would be helpful to direct our attention to natural phenomena occurring under such conditions that nothing but crystallization could have been effective, and examine the results. It is doubtful whether, in the absolute sense, rocks which meet this requirement can be found, but many surface basalts approximate to the requirements sufficiently closely for the purpose. They have probably received little or no contaminating material; a large part of their easily volatile ingredients has escaped before crystallization has proceeded far; convection currents have not obscured the results; and later hydrothermal action has not greatly affected them. It is, then, to such surface basalts that we should look for information.

In carrying out this idea a great number of thin sections of plateau basalts from different parts of the world were examined. It was found that in the great majority of instances, when crystallization was almost complete, the last little residue of magma in the interstices among larger crystals deposited felspar, pyroxene, and large amounts of magnetite. It was pointed out that the composition of the residue thus indicated was hardly compatible with the theoretical view that it should be of granitic or rhyolitic composition, as has been maintained in the theory of crystallization-differentiation.

In my argument the fact was not overlooked that plutonic bodies of apparently cognate origins vary in composition among themselves in such a manner as to indicate differentiation along lines quite different from that indicated by the study of basalts, but doubt was expressed

whether these differences could be attributed solely to the effect of crystallization.

For most igneous magmas the site of differentiation is necessarily placed in the deeper regions of the lithosphere, as they arrive at or near the surface in an already differentiated condition. However, although most plutonic bodies show little or no differentiation after emplacement, yet a considerable number do exhibit differences of composition of one kind or another within their mass, and all these have been claimed to be examples of crystallization-differentiation by those who recognize no other process of differentiation. For some of these bodies I would readily grant that crystallization has been an important factor, but for others I would feel much doubt, and in some instances there seems reason to question whether some of the results attributed to crystallization-differentiation have been effected within a liquid magma at all, but rather to suppose that they are post-consolidation effects or results of intense alteration of wall rock. In general, I suspect that many phenomena which have been cited as evidences of crystallization-differentiation need further consideration to make sure that they are not due in part to other processes.

Some explanation and amplification of these statements may be desirable in order to present a more concrete picture. We know that in some manner a separation of magmatic ingredients has been effected, but the question here raised is whether we are yet in a position to assume that crystallization has been the sole agent in bringing this about. We may not be able to point with confidence to any other process to meet the demands, but this is not a prerequisite for a consideration of the evidence.

Among processes for effecting separation we may regard crystallization as a factor of large possibilities, and sublimation of volatile compounds also must be an effective agent, but it is not plain that, alone or in combination, they are able to meet all the requirements of all cases. Liquid immiscibility, formerly much favoured by some geologists, is apparently of very limited application in dry melts, but may be of more importance in natural magmas, though the evidence so far brought forward does not appear convincing. Diffusion is not a well known quantity. It has been shown to be exceedingly slow in its operation under certain conditions of experimentation, but the possibility has been suggested that various combinations of the lighter elements with bases may be more mobile, and when dissolved in a melt consisting chiefly of silicates may diffuse more rapidly than

the silicates themselves. The suggested process has some resemblance to Soret's principle, but differs in certain important respects; for example, that it is not an effect of differences of temperature but of the tendency of volatile material to escape from the system, and that chemical reactions between the magma and the escaping volatiles are involved in an important manner. It is not advocated here as a definitely known process, but is suggested as an example of unexplored possibilities.

With respect to crystallization-differentiation specifically, there seems reason to doubt whether the scope of the theory itself and the field relations have yet been examined with sufficient critical care, and assumptions seem to be involved which pass over wide gaps in both theoretical and field information. Moreover, some of its fundamental principles appear to be irreconcilable with what we find in the rocks themselves. Rhyolites and granites are looked upon as the last liquid residues from the cooling and crystallization of basaltic magma, and, *ipso facto*, direct solution and assimilation of basic rocks by rhyolites and granites, except in small amounts, are held to be impossible; but I have observed phenomena in the Katmai region and in Yellowstone Park which, I believe, cannot be explained otherwise than by solution, on a large scale, of basic andesites and basalts by rhyolitic extrusives, without loss of fluidity.[1]

In the face of such evidence I cannot believe that rhyolites represent simply the last remaining and coldest liquid derived from the crystallization of basalt. Some large source of energy is required which is not provided in the theory. In fact, assimilation on such a scale is expressly rejected by the theory and is contrary to the postulates on which the reasoning is based.

In another class of processes the effects produced may simulate those of crystallization-differentiation, while actually of quite different origin. Such effects may be brought about by the mingling of unlike magmas, successive injections of magma, assimilation of foreign material, post-consolidation endomorphism and substitutions in igneous masses, especially their upper portions, by gases and hydrothermal solutions; and the metasomatism of roof and wall rocks by emanations to such a degree that a wholly igneous aspect is brought about. In these suggestions there is little that is novel except, perhaps, the view that such features have led to confusion in inter-

[1] Detailed descriptions will be published later, after the necessary laboratory work has been done.

preting phenomena of differentiation. They represent essentially processes which have been advocated by geologists irrespective of theories of differentiation.

Singly or in co-operation all these may have played a part in one or another instance. There are still numerous processes indicated as probable or possible which require much further consideration. The nature of the magma itself as it exists in the depths of the earth, the quantity and composition of the dissolved gases, the energy content, how magmas originate and what causes them to move upward toward the surface, the effects of relief of pressure in releasing gases and changing equilibrium relations, in what manner the magma becomes emplaced among the surrounding rocks, are matters about which there have been many speculations but few fundamental conclusions so firmly established as to be generally agreed upon. The great simplicity of the theory of crystallization-differentiation has been a strong recommendation in its favour, but it may be a case of applying too simple a conception to an extremely complex set of phenomena.

It is not intended to imply that there is anything mysterious about magmas or that they transcend known physical or chemical principles or that they are not amenable to laboratory investigation, but at the best our knowledge of the fundamental causes of volcanism and of certain phases of its development is meagre. It is important to maintain a proper perspective in these matters, and to realize that experimental investigation in certain fields of volcanism has hardly been begun; in fact, in some respects our knowledge is so slight that it would be difficult to decide to what degree the conditions that might be chosen for experimentation corresponded to those of natural systems.

In addition to the large-scale phenomena of differentiation certain smaller features require consideration, such as felsic veins or dikes in basic rocks, and microgranitic and myrmekitic aggregates in similar bodies. These also have been included among the evidences or proofs of the nature of the residue left by crystallization. In my paper I recognized, and, in fact, emphasized the existence of such features, and propounded to those who attribute their formation to crystallization alone the problem of explaining the reason for such a difference in composition of residues in abyssal or hypabyssal rocks from those found in surface basalts in which crystallization was the only important factor.

Recognition of the fact that in surface basalts crystallization has caused variation in a certain direction, while in deep-seated rocks the residue may show variation in a quite different direction, was fundamental to my argument, but it seems to have escaped Dr. Walker's attention, for it is hypabyssal rocks that he has here studied. I do not find it surprising or inconsistent with my views that the residue left from the crystallization of tholeiitic dolerites should be somewhat at variance with what I found for surface basalts. In effect, what might appear, from a reading of Dr. Walker's paper, to be a problem for me to solve is essentially the problem that I had put before others. My own answer is simple: that in deep-seated rocks other factors than primary crystallization have participated. I shall enlarge upon this in discussing other features of his paper.

Before doing so, however, I will pass to a consideration of certain other articles which are closely related to the matters already touched upon. Attention may be called to what seems a similar misunderstanding at one point of Daly and Barth's discussion of certain features of my paper, in their article on the Karroo dolerites, which appeared in the Geological Magazine for March, 1930.[1] They state that the picritic basalt of Hawaii is richer in total iron than the dominant Hawaiian basalt from which they believe the picritic basalt to have been derived by enrichment in olivine, and they believe that this does not support my contention that the early crystal fractionation of basaltic magma should enrich the residual liquid with iron.

This view, however, represents only a part of my argument. I did not suppose that differentiation should always give a liquid portion enriched in iron and a crystalline or partly crystalline portion impoverished in iron. That was the normal result observed in those cases where we could be sure that crystal separation had been the dominant factor, but it would only be generally true if crystal separation were generally the dominant factor—the very point against which the argument was directed. When results of another sort are observed, as is frequently the case, this fact itself suggests that somewhere along the line of differentiation some other process than crystal separation has intervened.

The relations that Daly and Barth supposed to be in opposition to my views are actually those cited by me in support of the argument. On this matter there is a great difference between the deductions that

[1] R. A. Daly and T. F. W. Barth, Geol. Mag. London, 1930, vol. 67, p. 109, footnote 2.

I sought to make and those ascribed to me by these authors. To put the thesis in the simplest terms, crystal separation alone, acting upon a basaltic magma, is observed to lead to a residual liquid rich in iron. In the differentiation of plutonic bodies this result is sometimes apparent, and in some of these instances we may confidently ascribe a leading role to crystal separation. Often, however, the derived liquid is poorer in iron than the original basaltic magma, and the participation of other processes is thus indicated.

In a later explanatory note on Karroo dolerites, contributed by Daly and Barth to the Geological Magazine for November, 1930,[1] it is shown that the FeO : MgO ratios for many derived basalts is lower than for the world plateau basalts. They contend that if these derived basalts have originated from the plateau basalts by the dropping out of olivine crystals, a higher FeO : MgO ratio should have been the result. I believe that this is a reasonable deduction, and that the lower ratio actually present is in accord with the argument I made, namely, that other processes than crystal separation have participated.

Of considerable interest in connexion with the subjects with which we are dealing is a recently published article by Bowen, Schairer, and Willems on the system Na_2SiO_3–Fe_2O_3–SiO_2.[2] In their article the various reactions that may take place under different conditions are brought out, but it is only with a part of the results that we are concerned here. It is shown, as one of the characteristics of the system, that several compounds which crystallize from the cooling melt may later be wholly or partly resorbed, and may or may not again appear. From this it follows that very different final results may be obtained according to whether or not a reactive mineral of this kind remains in contact with the melt or is removed or in any manner protected from reaction. They show that in this system the final product may be in one case an aggregate in which haematite is present and in another case may be of very different composition, without haematite but with quartz as one of the constituents. A petrologic application is made in the suggestion that in a similar manner the iron-bearing silicates of a basalt may exhibit discontinuous reaction relations with the liquid and thus present the possibility of obtaining, through alternative courses of crystallization, an iron-rich residue containing magne-

[1] R. A. Daly and T. F. W. Barth, Geol. Mag. London, 1930, vol. 67, p. 481.

[2] N. L. Bowen, J. F. Schairer, and H. W. V. Willems, The ternary system: Na_2SiO_3–Fe_2O_3–SiO_2. Amer. Journ. Sci., 1930, ser. 5, vol. 20, pp. 405–455.

tite or a residue of granitic or syenitic composition. This is indicated as an answer to the problem propounded in my article. The idea is expressed in the following terms:

> 'Alternative courses of a quite parallel character are demonstrated . . . in the present system. The parallel is even greater than it may seem because in the present system low fractionation gives the iron-rich final liquid and high fractionation the siliceous liquid, and it is in the quickly cooled (and therefore ordinarily little fractionated) basalts that the late crystallization of iron-rich liquid has been urged, and in the more slowly cooled dolerites (and in sub-alkaline series of rocks formed *ex-hypothesi* by crystallization-differentiation) that the late crystallization of siliceous liquid has frequently been well demonstrated' (Bowen Schairer, and Willems, op. cit., p. 451).

According to this explanation, it is necessary, in the crystallization of a basaltic liquid, to separate crystals from liquid at a certain stage in order to obtain a siliceous final liquid, otherwise later reaction between solid and liquid phases will lead to an iron-rich residue. This represents some modification of previous views of Dr. Bowen regarding the course of crystallization in a basaltic magma. There seems to be recognition that the theory in its earlier form was not sufficient to acccount for the iron-rich residue found in basalts. I doubt if the new suggestion offers a solution of the problem.

It is a far extrapolation from a system of the composition with which these authors here deal to that of a basaltic magma. The resorption of a constituent by the liquid, and the results attendant upon it, are of the sort that occurs in any crystallizing system in which an incongruently melting constituent appears, and such constituents are of common occurrence in systems experimentally investigated. It would be more convincing to give some evidence that in actual basaltic magmas the iron minerals break up in similar fashion at the right stage or are separated from contact with liquid in the right way to produce the required effects.

In the system experimentally investigated by these authors it was ascertained that no compound was formed between Fe_2O_3 and SiO_2 alone, but that the presence of considerable Na_2O is essential, and this fact may have much to do with the characteristic properties of the system. In natural magmas of basaltic composition the relations between iron oxides and silica appear to be quite different. A large amount of the FeO present (together with MgO and CaO) enters into firm combination with silica, as metasilicates, and the resulting crystalline minerals take up Fe_2O_3, either in solid solution or in some

other form of combination, and hold it tightly bound. Very different results may therefore be expected in the different cases.

The authors seem to imply that it is only in the quickly cooling surface basalts that iron-rich residues are obtained. It is, in fact, in such rocks that the evidence is most plain, for in these the complications from other possibilities are least, and therefore it was on these that I laid most emphasis, but I pointed out evidence of the not unusual presence of considerable amounts of magnetite and biotite of late crystallization in diabases (dolerites) also, as illustrating the occasional occurrence of a similar course of crystallization under hypabyssal conditions, although believing that in these rocks other processes frequently introduce complications due to entirely different factors.

In the system Na_2SiO_3–Fe_2O_3–SiO_2 the diagrams show that under certain assumptions almost as much iron may be present in the final residue as in the original melt, and the authors regard this as an important matter, but in basalts the iron minerals in the last residues are often obviously greatly in excess of the amount in the original magma, and not only is magnetite prominent, but pyroxene as well.

The previously quoted article and supplementary note by Daly and Barth lead to inferences that have a further bearing on the article now under consideration. As already mentioned, the work of Daly and Barth indicated that certain basaltic magmas derived at an early stage from a general parent magma show a lower FeO : MgO ratio than the original magma, and it is difficult to explain such a result by any principle brought out in connexion with this experimental investigation, for the authors recognize without question that the separation of FeO–MgO minerals tends to increase the FeO : MgO ratio in the liquid.

In this experimental system, as in many other silicate systems which have been investigated, the breaking down of reactive minerals in the process of cooling throws SiO_2 into the liquid, and this is deemed of great theoretical importance in arriving at a final liquid with excess quartz. The prevalence of this phenomenon is curious, and it may have significance as a co-operative factor in petrogenic processes. Let us not forget, however, that among the actual magmatic minerals of common occurrence it is not obvious that this tendency is of great importance except for the appearance of olivine in basalts in regions of composition where the normative mineral is pyroxene. Moreover, in accomplishing such reactions pneumatolytic processes seem actually

to be more effective than processes occurring in melts. In acid andesites and even in rhyolites, gas bubbles and other cavities or porosities of the rock frequently contain olivine or haematite, together with one or more of the silica minerals. We should remember, too, such phenomena as those described by Dr. Zies for the Valley of Ten Thousand Smokes, where, in a single small area of fumarolic activity, gases rising from a rhyolite had deposited several thousand pounds of nearly pure magnetite.[1] Also 'during one of the eruptions of Vesuvius a fissure 3 feet wide was thus filled with hematite in a few days.'[2]

Not only orthomagmatic processes but thermal waters also have the effect of separating quartz even from very basic rocks, and some of the quartz of late crystallization in basic rocks attributed to orthomagmatic processes may in fact be a hydrothermal product. In the well-known deposits of zeolites and associated minerals in the Watchung basalts of New Jersey probably the most abundant single mineral is quartz, of which rather large masses occur. This and albite were among the earliest minerals of secondary origin deposited.[3] Babingtonite and an acicular green mineral which is probably aegirine also appeared at an early stage of postmagmatic alteration. Progressive changes ensued as the solutions cooled, and the final result of these secondary processes was to remove nearly all the iron, magnesia, and titania from certain parts of the original rock, and leave little but silica, alumina, lime, and the alkalis (together with some B_2O_3, fluorine, CO_2, and SO_3) in various mineral combinations. One may ask whether similar aqueous solutions, at a somewhat higher temperature, circulating in zones of fracture and crushing, would not form dike-like bodies of quartzo-felspathic character distinguishable with difficulty from true dikes of orthomagmatic derivation, and whether certain bodies of this sort which have been interpreted as of orthomagmatic origin are not due to hydrothermal action.

[1] E. G. Zies, The fumarolic incrustations in the Valley of Ten Thousand Smokes. National Geogr. Soc. Washington, Contrib. Tech. Papers, 1924, Katmai ser., vol. 1, no. 3, p. 166 [Min. Abstr., vol. 2, p. 439].

[2] L. V. Pirsson and C. Schuchert, A textbook of geology. 3rd edition, 1929, part 1, p. 267.

[3] The secondary minerals occur chiefly in the interstices among the boulder-like masses of an extrusive pillow-lava. The conditions of occurrence show that the minerals are due to the action of thermal waters of ultimately meteoric derivation. The possibility that they represent in any sense residues from orthomagmatic crystallization is eliminated.

As bearing upon the general relations of iron compounds to other components of magmas, and the possibility of their removal by crystallization to give residues poor in iron, the authors argue that in the competition in a crystallizing magma between the two principal solid solution series—plagioclase felspars and iron-bearing metasilicates (e.g. pyroxenes)—it is not possible to tell with our present knowledge which side will prevail in the diminishing residual liquid. Strictly, this is true, but there are certain general principles which control the result and give a suggestion of what is likely to occur.

The competition is chiefly between the lowest melting plagioclase felspar—albite—and the lowest melting pyroxene, which may be either ferrous metasilicate, ferrous calcium metasilicate, or some still more complex mineral compound. The final result, with respect to the relative amounts of plagioclase and iron-pyroxene left in the liquid, is dependent upon two physical properties of the two competing minerals—the temperature of melting and the molar heat of melting (or solution). For albite these properties are almost exactly known from Dr. Bowen's determinations; for the iron-pyroxenes experimental investigations encounter the difficulty that is always present in dealing with iron minerals—the difficulty of preserving the state of oxidation unaltered; therefore, our knowledge of these properties is not at all exact. What little evidence we have hardly indicates that the physical properties of the iron-bearing pyroxene are so different in these respects from those of albite that we should expect to obtain as a result of crystallization the overwhelmingly large amounts of albite and the vanishingly small amounts of iron-pyroxene (or its equivalent) that we find in many rhyolites and granites.

This has a bearing of some importance upon the theory of crystallization-differentiation. The view adopted in the theory is that iron metasilicates are almost completely eliminated by crystallization, as this assumption is necessary to obtain a magma of rhyolitic composition, but this can hardly be said to rest upon either experimental or theoretical evidence except of the vague sort explained above, which, as far as it goes, seems to point in the contrary direction. It is likewise opposed by the continuance of pyroxene in the last residues of basalts, as explained in my previous paper. There is here an important gap in the theory, and the bridge across it rests upon an assumption for which evidence is lacking.

In the theory of crystallization-differentiation an outstanding feature is its elasticity. In systems containing reactive constituents

so many possibilities of alternative courses of crystallization are open and so little is known about directive or restraining influences, that a great variety of results may be obtained by supposing certain reactions to have occurred or to have been prevented, or by supposing that separation of crystals and liquid has or has not been brought about at the proper moment. A theory of so many inherent possibilities lends itself to the ready explanation of what has been found to occur, but is not of great assistance in predicting what is likely to occur. This characteristic is apparent throughout the literature of the subject. The great desideratum at present seems to be more concrete evidence from the rocks themselves that processes occur in the manner and of the sort postulated. In the basalts that I have studied there seems to be nothing in the present relations of the constituents that indicates the processes suggested by Dr. Bowen and his collaborators to explain the formation of iron-rich residues. So far as may be deduced from thin sections the course of crystallization brought about the precipitation of plagioclase, pyroxene, and magnetite almost from the beginning, and an uncomplicated continuance of deposition of these three minerals to the end, with magnetite in large amount in the final residue.

In considering petrogenic processes one may doubt also whether ' filter-pressing ' and ' armouring of crystals '—processes of undoubted reality in a limited sense—are really so widely prevalent or effective in differentiation as is often assumed, or whether invoking them when required to assist in explanation does not give to the process a somewhat artificial aspect; also whether the fact that such widely different processes as magmatic crystallization on the one hand and hydrothermal metamorphism (accompanied by metasomatism) on the other frequently give the same or closely similar mineral assemblages has not led to confusion and misinterpretation of evidence.

Let us return now to Dr. Walker's paper and consider certain other matters contained in it, on which differences of interpretation from those given by him may be allowable. On page 376 Dr. Walker states:

' Both tholeiites support Dr. Fenner's contention that iron is concentrated in the residuum of basaltic rocks; for the chlorophaeite—a mineral rich in iron—is of late formation in both rocks and so is the ilmenite in the northern exposures of Kinkell quarry. The author believes, however, that this late crystallization of minerals rich in iron left a still later residue much poorer in that constituent—a constituent whose presence in any abundance would raise the refractive index of the glass far above the recorded values.'

I had suggested in the article referred to that in the crystallization of basalts (and, *a fortiori*, of dolerites or diabases) there should be a tendency for certain minor elements to be concentrated in the last residue, and possibly a sufficient amount of borates, phosphates, and silicofluorides might sometimes be retained to lower the refractive index of the glass, especially if at the same time iron were carried away as a volatile halide. This idea was tested to some degree by Dr. Walker by having a spectrographic examination and a quantitative estimation made of boron in the Dalmeny rock. It was 'proved conclusively that boron was present. . . . Phosphate cannot be present in the glass, for the normative and modal apatite agree closely in both rocks. It is, however, extremely doubtful if the presence of B_2O_3 in the glass (in this case under 1 %) would lower the refractive index, for the three best-known boro-silicates, tourmaline, axinite, and dumortierite, all have high refractive indices'.

In Dr. Walker's specimens the amount of glass in the rock was relatively large, while my suggestion referred to rocks in which crystallization had proceeded so far that only small amounts of glass were left in which these minor constituents may have become concentrated. With the increased concentration of B_2O_3 thus affected, Dr. Walker's finding of boron seems to give some support to my suggestion rather than the contrary. As for lack of phosphates the validity of the evidence cited by Dr. Walker appears doubtful. In the description of one of the rocks he says that 'numerous needles of apatite may be detected in the mesostasis'. This indicates, at least, that phosphates had been thrown into the residue during the later stages of crystallization of the main constituents, and I doubt if it is possible to estimate the quantity of such acicular apatite crystals in the mode exactly enough to be certain that some quite significant percentage of occult phosphate may not be contained in the glass.

The difficulty of exact determination of modal quantities in these rocks is shown by certain other figures given by Dr. Walker. For the southern Kinkell rock, iron-ore in the mode is given as 17·6 %. From the accompanying analytical figures it appears that this would use up all the FeO, Fe_2O_3, and TiO_2 present, leaving none for the chlorophaeite, enstatite-augite, or glass, which is obviously impossible.

On the suggestion that iron may be volatilized as a halide from the last residues, no evidence is contributed by Dr. Walker other than

the expression of belief that it was eliminated by crystallization, as quoted above. On the other hand, the view that the removal of iron in volatile combination is a factor during the magmatic history, and especially near the end of crystallization, is supported by considerable evidence. An instructive experiment which illustrates the process may be easily performed by mixing a little sodium chloride with powdered basalt, and heating the mixture in a covered platinum crucible. Iron is volatilized as chloride and then, in contact with air, is deposited as haematite. The small haematite scales often observable in porous andesitic and rhyolitic lavas appear to be of analogous origin; likewise the fumarolic magnetite deposits in the Valley of Ten Thousand Smokes, and deposits of magnetite and haematite elsewhere.

In connexion with some intrusive bodies, removal of great quantities of iron at a late stage of magmatic history is exemplified in pyrometasomatic ore-deposits of magnetite and associated minerals. Whether, in such instances, one attributes the removal of iron from the parent body to gaseous emanations or to aqueous solutions, it seems that the intrusives from which they have been derived have been deprived of a portion of their iron by processes not closely correlated with crystallization-differentiation.

The economic importance of ore-bodies of this category has directed much study to their relations, but chiefly to the exomorphic phenomena of which they are a part. There must, however, be equivalent endomorphic changes. In fact, they illustrate a set of processes of general character, by which a crystallizing and cooling mass of rock is penetrated and searched out by migrating gases and hydrothermal solutions. Some of the results of this action have been determined, but it is doubtful if all the effects have yet been recognized. It seems to have been satisfactorily demonstrated by various workers that micropegmatites, myrmekites, and similar aggregates have often been formed by such post-magmatic processes, and, in the face of this, it is hardly safe to assume, without more evidence than has been contributed, that the presence of aggregates of this character in the interstices of dolerites (diabases) is to be attributed to the final stage of magmatic consolidation. In relation to this Dr. Walker makes statements with which I can hardly agree. He says (p. 735):

'Had the glass been permitted to crystallize it would, doubtless, have formed the interstitial micropegmatite so characteristic of the British Permo-Carboniferous quartz-dolerites. It may be added at this point that there is no evidence

that this micropegmatite is of deuteric formation, for it may be found in absolutely fresh rocks (e.g. that of Auchterarder station). Hydrothermal alteration has certainly taken place in some examples, and it may be detected by the albitization or analcitization of the plagioclase which it causes. The light quartzofelspathic veins which so commonly represent the last magmatic residue often contain twinned albite-oligoclase and acicular hornblende or augite, which cannot be regarded as other than normal products of crystallization.'

In this statement Dr. Walker apparently makes his chief criteria of lack of hydrothermal alteration the fresh appearance of the rocks and the fact that oligoclase-albite has not been albitized or analcitized. If this were accepted as a standard of general applicability it would seem to bar any fresh rock in which oligoclase or oligoclase-albite is present from being regarded as a product of hydrothermal metamorphism. Many petrologists hold different views. In a late issue of the Mineralogical Magazine Dr. F. C. Phillips[1] expresses a principle of probably general applicability in metamorphism as follows: 'In low-grade dynamic metamorphism the reconstituted felspar is a pure albite, but as the metamorphic grade increases a more calcic member of the series becomes stable.'

Professor Sederholm, who has made very thorough studies of myrmekitic structures, states that the felspar is commonly an oligoclase-albite, and concludes that, in most cases at least, these structures have been formed by circulating solutions and gases after the primary consolidation of the rock.[2] We may quote also from a recent publication of Knopf and Anderson:[3]

'The resultant ores and rocks seem unaltered to the unaided eye and have therefore that appearance of "lack of hydrothermal alteration" so commonly cited in support of the orthomagmatic origin of certain ore deposits. Rocks in which actinolite, biotite, and plagioclase have formed metasomatically are bound to look fresh and unaltered; in fact, it is characteristic of pneumatolytically altered rocks to have that appearance.'

Likewise many of the phenomena of granitization described in the classic works of Adams and Barlow on the Haliburton-Bancroft region, of Sederholm on certain areas in Finland, and of Lacroix on the Pyrenees, give contributory information. Thus we have excellent authority for believing that pneumatolysis or a high grade of hydro-

[1] F. C. Phillips, Some mineralogical and chemical changes induced by progressive metamorphism in the Green Bed group of the Scottish Dalradian. Min. Mag., 1930, vol. 22, p. 247.

[2] J. J. Sederholm, On synantetic minerals and related phenomena. Bull. Comm. Géol. Finlande, 1916, no. 48.

[3] A. Knopf and C. A. Anderson, The Engels copper deposits, California. Econ. Geol., 1930, vol. 25, p. 33.

thermal metamorphism frequently produces the same or very similar assemblages of minerals as orthomagmatic crystallization, and this is a source of very real difficulty in petrogenic interpretations.

There is a large group of phenomena of this sort to which much more investigation should be devoted before satisfactory criteria can be established for determining in what manner various examples have originated, and a first requirement in such researches seems to be recognition of the fact that certain phenomena of alteration brought about by hydrothermal processes at low or moderate temperatures should not be expected to result when the conditions are those of high-temperature metamorphism or pneumatolysis, nor is lack of fresh appearance to be looked for under these conditions. Dr. Lindgren has stated: 'Complete recrystallization, development of silicate minerals with little or no water, and coarse texture are typical of deposits formed by replacement at high temperatures, probably above 400°.'[1]

It should also be recognized that in replacement processes minerals of secondary formation frequently crystallize with idiomorphic boundaries (metacrysts). So many examples of this have been described and they are of such common occurrence that it would hardly be necessary to call attention to the fact were it not that it seems to be frequently overlooked, and assignment of a mineral to a primary origin made on the basis of its idiomorphic outlines.

In not a few descriptions, alteration effects which have been pointed to as illustrating the reaction principle in magmas, seem equally explicable as results of hydrothermal metasomatism. Processes so fundamentally unlike may lead to almost identical results, and the implications and conclusions to be drawn are entirely at variance.

Acceptance of the essentially magmatic origin of great bodies of plutonic rocks should not cause us to attribute everything found in them to primary magmatic processes. Probably all such bodies have been subjected after consolidation to the action of autogenous (and perhaps xenogenous) vapours and solutions, and it remains to be determined to what degree such phenomena as myrmekites and micropegmatites, and even larger features such as certain dike-like sheets of felsic minerals and variations of composition in different portions of a mass, are due to primary crystallization from a magma and to what degree they are the result of later pneumatolytic and

[1] W. Lindgren, Mineral Deposits, 3rd edition, 1928, p. 204.

hydrothermal replacement phenomena in an already consolidated mass.

In connexion with the tholeiites that Dr. Walker studied attention may be called to a series of tholeiite dikes examined by Holmes and Harwood,[1] which are regarded by them as outlying extensions of the Mull swarm. Some of these show an iron-rich mesostasis and some a quartz–alkali-felspar mesostasis, and they possess other puzzling characteristics. The authors point to the 'remarkable feature that wherever Tertiary tholeiites occur several different types are to be found in proximity' (p. 41). In endeavouring to find an explanation evidence of various kinds is discussed at considerable length. They find that 'differentiation by crystallization and separation of the residual liquid was not the process involved in the production of the different types of tholeiites', and conclude (p. 49):

'Our study, however, finally leads to the belief that there is no satisfactory alternative to the assumption of mixing by one process or another. Similar arguments apply to many of the puzzling rocks of Mull, such as inninmorite and the rocks of the "differentiation column"; to the common association of rocks of strongly contrasted composition in composite dikes and sills in Mull and other Tertiary centres; and indeed, to all provinces in which gabbros, dolerites, and basalts, on the one hand, occur dominantly with granites, granophyres, quartz-porphyries, and rhyolites, on the other, without any noteworthy development of intermediate types.'

The evidence that Holmes and Harwood have brought forward (presented in detail in their discussions) raises a justifiable doubt as to the validity of the crystal differentiation explanation of these occurrences, and their alternative explanation is supported in principle by many occurrences of strongly contrasted types of rock in other regions, but it is not certain that it offers the only explanation in all the cases to which they apply it. In regard to the composition of basaltic or tholeiitic glasses specifically, a subsequent change of composition may, in some instances, be of importance. The minerals deposited in the last stages of magmatic crystallization should be a good index of the composition of the magma (or glass) at that time, but after this period has come to an end it is questionable whether the composition of the glass that is finally left remains the same, even though the glassy aspect may be retained. This has been brought forcibly to my attention by some analyses I have recently made.

In the pillow-lavas found in certain areas of the Triassic Wat-

[1] A. Holmes and H. F. Harwood, The tholeiite dikes of the north of England. Min. Mag., 1929, vol. 22, pp. 1–52.

chung basalts in New Jersey each pillow is covered with a dark green to nearly black, shining to dull-shining crust of what appears to be nearly unaltered glass and has generally been so regarded. There is no doubt that it was originally a glassy phase of the basalt, but it has undergone a remarkable change in composition. Two specimens of material which were obtained several hundred feet apart in separate quarries at Paterson were analysed. Specimen W 401 A is the glassy looking crust, and W 401 B is the finely crystalline basalt immediately adjacent; W 402 A and W 402 B have similar relations. The analyses are not yet quite complete as regards certain minor constituents, but are sufficiently so for this purpose.

	W 401 A.	W 401 B.	W 402 A.	W 402 B.
SiO_2	43·39	52·43	46·88	52·33
TiO_2	1·43	1·13	1·20	1·09
$Al_2O_3+P_2O_5$ ...	15·25	14·36	15·75	14·29
Fe_2O_3	2·75	1·86	3·13	2·40
FeO	9·86	8·10	6·42	7·90
MnO	0.13	0·14	0·09	n.d.
MgO	10.70	7·22	9·31	7·20
CaO	4·66	9·82	2·64	10·43
Na_2O	2·21	3·44	0·57	2·40
K_2O	2·10	0·42	5·42	0·36
H_2O	7·59	1·18	8·53	1·62
CO_2	0·06	n.d.	n.d.	n.d.
	100·13	100·10	99·94	100·02

It is readily seen that while the two crystalline specimens (W 401 B and W 402 B) agree closely in composition, and are similar to other Watchung basalts, each differs remarkably from its contiguous glass. These results make one dubious whether any basaltic or doleritic glass, if not of absolutely fresh appearance, can be assumed to have the composition it had in the beginning. The striking fact is not that circulating waters, especially those of thermal character, should act upon this unstable material, but that they should effect such changes of composition without altering very conspicuously the physical appearance.

In these Watchung rocks the hand-specimens give little hint that the glass has been altered to any such degree as is shown by the analyses. In the thin section W 401 A gives likewise little indication of alteration; W 402 A shows more effect, but of a kind which, under less favourable conditions of observation and with less data, might lead to incorrect conclusions. Certain bands and irregular

areas are seen to have been bleached to a nearly colourless material of low refraction and very low birefringence. The relation of this bleached material to the adjacent glass, and the analytical figures, show that it is a result of alteration, which has changed the composition greatly; but if similar material, with its vague optical properties, were observed under ordinary circumstances among the crystalline areas of a basalt, it would probably be regarded as representing a glass little modified from its original character. Its low refraction and lack of colour would then suggest a residue of quartzo-felspathic composition.

These results may have an application to Dr. Walker's specimens and to others which have been described. In many such cases there seems to be no means of determining to what extent the isotropic or nearly isotropic material that is found should be considered to represent the composition of the original glassy residue. In any event, Dr. Walker's conclusion regarding the results of crystallization in the tholeiites is not, after all, so very different from what I found for basalts, and, on the other hand, it does not conform to the standard set by the crystallization theory. Dr. Walker believes that iron was concentrated in the residuum up to a late stage, but was removed before the final product was reached. According to this interpretation, the composition of the residuum during the intermediate and penultimate stages of crystallization was enriched in iron, and was therefore quite different from the composition of what should be the corresponding rocks of the crystal differentiation series—siliceous andesites or trachytes.

In examining the articles of Walker, of Daly and Barth, of Bowen, Schairer, and Willems, and of Holmes and Harwood, one is impressed with the different view-points regarding the phenomena in basaltic rocks that are the subject of discussion. It seems evident that more investigation of some fundamental problems is called for.

I am happy to observe that in another recent article Dr. Walker recognizes that other processes than crystallization have been factors in differentiation. He states:

'An examination of the literature of natural occurrences indicates that even the best-known type-examples possess some features which prevent them from being entirely convincing. Other processes of differentiation, or subsequent intrusions, may, for instance, conspire to confuse the issue.'[1]

[1] F. Walker, The geology of the Shiant Isles. Quart. Journ. Geol. Soc. London, 1930, vol. 86, p. 374.

I should be inclined to add to this that often post-magmatic processes, of the sort we have discussed, similarly confuse the evidence, but, on the whole, the attitude expressed by Dr. Walker, and the consequent desirability of refraining from attributing all phenomena of differentiation immediately to crystallization but attempting to discriminate among the various processes, represent essentially what I have urged for several years. It is only by examination and discussion of the evidence that agreement may finally be reached.

The principal subject of the present article has been the discussion of the character of the residues left by the crystallization of magmas, especially in their relation to certain features which have been held to support the view that crystallization has been the only effective agent in differentiation. It has been pointed out here that in many instances a reasonable doubt may be held as to whether these features have originated in the manner assumed, and whether the conclusions to which they are supposed to point are justified.

It hardly comes within the scope of the article to discuss in detail the broader problems of differentiation, but as this is the subject toward which all the discussion tends, I wish to add a short summary of some of the outstanding points of evidence that, I believe, should be taken into consideration in forming an opinion on the matter. These may be listed as follows:

Features which appear to be inconsistent with the present theory of crystallization-differentiation are:

1. The observed ability of rhyolites, and probably granites, to dissolve large quantities of basic rocks. This evidence is a matter of field observation, and is directly opposed to the fundamental conceptions of the theory in its present form.

2. The nearly linear variation of composition often shown in rock series. This feature is well illustrated in the rocks of the Katmai region.

3. The difficulty of explaining by this theory the origin of many monomineralic and bimineralic ultrabasic bodies—anorthosites, pyroxenites, dunites, bodies of magnetite or chromite, &c.—without resort to auxiliary hypotheses which appear artificial and speculative. This is exemplified in the remarkable banded rocks of the Bushveld complex, where the presence of sharply defined layers of anorthosite, magnetite, chromite, bronzitite, &c., and their repetition in the sequence at widely separated levels are characteristic features. In other regions monomineralic and bimineralic basic rocks appear to

occur as true intrusive dikes, some of which likewise are very difficult to explain.

4. The occurrence, in some regions, of alternate outpourings of typical basalt and typical rhyolite, with little or no lava of intermediate composition, throughout a volcanic period. There is difficulty in bringing this phenomenon into accord with any idea of differentiation, and especially with the theory of crystal fractionation. It has the appearance of discontinuous variation, and, if it stood by itself, one would suppose that the sharp contrast of products, without intermediate gradations, would indicate independent genesis of the two types of lava. The floods of Pliocene basalts and rhyolites of the northern part of Yellowstone Park (probably fissure eruptions) illustrate this alternation. It is among them that the previously mentioned examples of assimilation of basalt by rhyolite have been found.

5. The lack of agreement in the composition of the residue left by the crystallization of surface basalts with the requirements of the theory. Closely related to this is the decrease in the FeO : MgO ratio in certain plutonic magmas under conditions where the theory indicates an increase; also the gap in evidence to support the view that crystallization would be more effective in eliminating iron-pyroxene (or its equivalent) than in eliminating albite from the magma.

Considerations which should be kept in mind in applying any theory of differentiation are :

6. The doubtful and ambiguous character of some of the evidence, as emphasized in the present paper. In many plutonic masses and occasionally in surface lavas differences of composition among the various parts may have been brought about, not by true differentiation, but by post-consolidation processes, of which the effects simulate closely those of differentiation in the liquid magma, and are likely to cause confusion and misinterpretation.

7. Confusion may similarly be caused by such processes as mixing of magmas before injection, or by successive injections, or by solution and assimilation of foreign material.

8. It should be recognized that any process tending to bring about a separation of a magma into relatively light and heavy portions will result eventually in density stratification. Separation of crystalline phases of greater or less specific gravity is not the only means by which density stratification may be brought about, and evidence of density stratification is not necessarily evidence of crystal fractionation.

For the eventual development of a satisfactory conception of the processes by which differentiation has been effected we may recognize at present:

9. The indubitable efficacy of crystal separation in some instances, and the theoretical necessity that such a process should effect changes of composition. The objections to considering it the sole process have been discussed in this and other papers.

10. The proven occurrence of mineral-bodies formed by sublimation, and the theoretical necessity that mineral matter should be removed from the magma in this manner. The chief uncertainty in determining the quantitative magnitude of operation lies in the fact that in many instances bodies of this origin have probably been modified by later hydrothermal action and their characteristics obscured, or the sublimates may have escaped into regions beyond observation. The process can hardly be the chief factor in differentiation, but may be important in modifying the effects of other processes.

11. Finally, we should have proper appreciation of our lack of knowledge of some of the fundamental properties of magmas, and recognize the possibility that some process not yet manifest to us may have participated in a fairly simple but effective manner.

Notes on brown hornblende and biotite from Shabō-zan, of the Daiton volcanoes, Taiwan, Japan.

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[Communicated by Prof. P. G. H. Boswell, F.R.S.]

Introduction.

THE Daiton volcanoes include all the volcanic groups which rise up at the north-western end of Taiwan (Formosa). They are old extinct volcanoes underlain by highly disturbed Tertiary sediments. Among them Shichisei-zan is the highest and the most prominent, rising up to 1108·7 metres above sea-level. It is mostly made up of hornblende-andesite, hypersthene-hornblende-andesite, and agglomerates. On the western slope of this partly dissected volcano there is a very characteristic cone called Shabō-zan. Its elevation is 643 metres above sea-level, and it is mostly made up of hypersthene-hornblende-andesite poured out through the thick accumulation of agglomerates. The andesite here has usually a grey colour, but often passes into a light reddish-brown variety, being sometimes associated with a noritic segregation mass. It is noteworthy that some of the andesites abundantly contain brown hornblende. This mineral also frequently appears, together with brown biotite, in the segregation mass. The writer first collected these minerals from its northern slope in the summer of 1929, and his attention has been attracted to their very characteristic pleochroism. The subject has already briefly been dealt with in his recent paper.[1] The brown hornblende here is easily mistaken for barkevikite, while the brown biotite somewhat resembles that in alkali-rocks. The minerals are, however, the alteration products from original varieties, and many specimens collected from various places show the different stages of transition between them. Hence, it is very interesting to compare the mode of occur-

[1] T. Ichimura, On the segregation masses contained in the hypersthene-hornblende-andesite from Shabō-zan Taiwan. [Japanese.] Trans. Nat. Hist. Soc. Formosa, 1929, vol. 19, pp. 406–409.

rence with that of basaltic hornblende associated with anomitic biotite in the quartz-andesite of the volcano Sambé.

The writer wishes to thank Prof. P. G. H. Boswell for his kind reading of the manuscript. He is also much indebted to Mr. T. Kōno, of the Taihoku Imperial University, for his chemical analyses of specimens.

Andesite and its noritic inclusions.

It is necessary to give here a short description of the andesite and its noritic inclusion from Shabō-zan before the writer goes on to discuss the brown hornblende and biotite. The andesite under consideration is composed of plagioclase, hornblende, hypersthene, augite, magnetite, and haematite. It is a rough and porphyritic rock with abundant phenocrysts of plagioclase, hornblende, and hypersthene. The plagioclase ranges from andesine to labradorite, both grading into each other toward the interior of the crystal. Although they are often alternately arranged, the outer portion of the crystal is usually more acidic than the interior. A general feature in this case is the presence of a turbid zone. Besides hornblende, the predominant ferromagnesian mineral is hypersthene, which is intimately associated with it, showing a stout or long prismatic habit. It is always characterized by straight extinction and the following pleochroic scheme: α and β light brown, γ light greenish-grey. Absorption is $\gamma < \beta = \alpha$. Optically it is negative. This mineral is also found as minute crystals in the groundmass. Augite is, on the other hand, a minute ingredient of the groundmass and takes a slender prismatic or granular form. Octahedral or granular magnetite is also a common constituent associated often with hornblende and hypersthene. The groundmass shows an orthophyric or pilotaxitic texture, consisting of the above-mentioned minerals. Plagioclase in the groundmass takes a rectangular habit in the orthophyric variety, whereas it is of slender lath form in the pilotaxitic one.

The noritic mass consists of granular aggregates of plagioclase, hornblende, hypersthene, augite, apatite, magnetite, biotite, and haematite. The plagioclase is of a more basic variety than that of the hypersthene-hornblende-andesite. The index of refraction is as follows: $n_1 = 1{\cdot}5745$–$1{\cdot}5755$, $n_2 = 1{\cdot}5790$–$1{\cdot}5812$ on (010). Hence the mineral belongs to the variety ranging from bytownite to anorthite. It is also remarkable that such plagioclases are not so distinctly zoned as usually shown in the andesite. Other points of difference are

the occurrence of apatite and biotite in this rock and the weak resistance to weathering. Both rocks occasionally show a gradual transition into one another, but commonly a well-bordered outline is seen between them.

The brown hornblende.

Crystal form and optical properties.—The brown hornblende usually takes a prismatic habit. It often shows very good crystal form in the andesite. When it is euhedral, the following faces are observed: $a(100)$, $b(010)$, $m(110)$, $p(\bar{1}01)$, and $r(011)$. In the andesite it occurs as phenocrysts and also as minute ingredients of the groundmass. The largest crystal is 2 cm. in length. In thin section it has a characteristic pleochroism: viz., α amber-yellow, β yellowish-brown, γ reddish-brown. The absorption is $\gamma > \beta > \alpha$. It is quite different from common basaltic hornblende, in which the pleochroism is α light yellow, β brownish-yellow, γ dark yellowish-brown; absorption is $\gamma > \beta > \alpha$. The extinction-angle of the brown hornblende is very small, viz., $\gamma : c = 0°–2°$; while in the basaltic hornblende $\gamma : c = 2°–10°$. It is optically negative. Indices of refraction in the type specimen are α 1·685, β 1·711, γ 1·731. Birefringence, $\gamma - \alpha$ 0·046, 2V 82° 20′. The plane of the optic axis is parallel to (010) and the acute bisectrix coincides with a. Some of the crystals show a twinning on (100). Most of them contain such inclusions as plagioclase, hypersthene, and magnetite. In the noritic mass the hornblende includes minute crystals of apatite and biotite together with the above-mentioned minerals. Plagioclase here is mostly found as patches and is the most prominent inclusion in hornblende. Moreover, the hornblende is generally subjected to magmatic resorption, and the crystals are partly or wholly changed into the minute aggregates of augite, magnetite, and haematite. Besides the characteristic pleochroic scheme, the brown hornblende is optically different from basaltic hornblende in its higher index of refraction and birefringence. However, various intermediate stages between brown hornblende and basaltic hornblende may be noted, and these gradually change in their optical properties in the same specimens.

Chemical composition.—A chemical investigation of the brown hornblende has recently been carried out by T. Kōno on the type specimen from the southern slope of Shabō-zan. According to his study the mineral is characterized by an exceedingly small percentage of ferrous oxide. The percentage of FeO reaches 8·21 in the basaltic

hornblende from the same locality which was also chemically analysed by T. Kōno. The colour of this mineral seems to be partly due to the lack of ferrous oxide. The percentage of Na_2O is, of course, much lower than that of barkevikite. It is also interesting to compare them with the chemical composition of the basaltic hornblende from Germany as shown in (3), (4), and (5).

The results of chemical analyses of brown hornblende and basaltic hornblende are as follows:

	(1).	(2).	(3).	(4).	(5).
SiO_2	40·69	39·48	40·82	40·62	41·38
TiO_2	2·98	3·10	4·06	4·07	2·93
Al_2O_3	12·09	10·97	14·21	14·74	13·44
Fe_2O_3	11·83	11·23	7·36	8·29	8·97
FeO	0·21	8·21	4·97	5·21	5·06
MnO	0·70	0·53	—	--	—
MgO	14·34	10·30	11·99	12·41	12·36
CaO	11·85	13·65	12·27	11·37	11·70
Na_2O	2·45	0·99	2·13	2·20	2·48
K_2O	1·56	0·67	1·15	1·06	1·23
P_2O_5	0·10	0·24	0·83	0·67	0·87
H_2O	—	—	0·49	0·43	0·39
Ign. loss ...	1·24	1·49	—	--	—
Total ...	100·04	100·86	100·28	101·07	100·81
Sp. gr. ...	—	—	3·231	3·223	3·198

(1). Brown hornblende from the southern slope of Shabō-zan, Taiwan. Analysed by T. Kōno.
(2). Basaltic hornblende from the same locality. Analysed by T. Kōno.
(3). ,, ,, Todtenköpfchen, Gersfeld,
(4). ,, ,, Sparbrod,
(5). ,, ,, Kleiner Suchenberg,
} Rhön Mts., Germany.[1]

Y. Deguchi [2] formerly reported the occurrence of barkevikite in the lavas of Shichisei-zan, but he did not say anything about its optical properties and chemical composition. It seems not to be different from the brown hornblende now under investigation by the writer. The hornblende here is also distinguishable from barkevikite in its optical properties.

The brown biotite.

The occurrence of biotite is restricted to the noritic inclusions in the andesite. It is found in minor quantity, and has a tabular

[1] X. Galkin, Chemische Untersuchung einiger Hornblenden und Augite aus Basalten der Rhön. Neues Jahrb. Min., 1910, Beil.-Bd. 29, pp. 689, 688, 694.

[2] Y. Deguchi, Geological report on the Daiton volcanoes. [Japanese.] P. 28.

habit which is characterized by the distinct cleavage parallel to the base. The mineral is usually associated with hornblende, and shows a remarkable pleochroism, α amber-yellow, β and γ bright reddish-brown with a yellowish shade. The absorption is $\beta = \gamma > \alpha$. The pleochroism of the brown biotite is thus quite different from the variety associated with basaltic hornblende. Absorption is sometimes variable along the basal cleavage. The birefringence is very high. Optically it is negative and 2V is very small. It often includes small patches of bytownite and anorthite together with magnetite. Sometimes it is included in hornblende and in this case there are frequently observed the minute aggregates of augite and magnetite along the contact. The index of refraction of the brown biotite has not yet been determined and the mineral has not yet been chemically investigated, for it is only accessory in the specimens collected by the writer.

Microscopical observations of various alteration stages in the andesite and its noritic inclusions.

The writer collected many specimens of andesite and its noritic inclusions from different parts of Shabō-zan to examine the alteration stages of the hornblende and biotite under the microscope. From those investigations it is evident that unaltered basaltic hornblende is almost restricted to the grey variety and its noritic inclusions. It is noteworthy that the hornblende here is mostly subjected to magmatic resorption and partly changes into minute aggregates of magnetite and augite. Such phenomena are more remarkable in the andesite than in its noritic inclusions. In a slightly altered specimen, the hornblende acquires a little different colour, a reddish-brown shade, showing more or less stronger pleochroism than before, viz., α light brownish-yellow, β dark yellowish-brown, γ dark brown with a reddish shade. Sometimes it exhibits different stages of alteration even in the same crystal : in this case a less-changed core of somewhat mottled colour is to be seen in thin section. The alteration usually begins from the outer side and gradually proceeds into the interior, until the mineral entirely attains such a typical pleochroic scheme as mentioned before : viz., α amber-yellow, β yellowish-brown, γ reddish-brown. In association with this alteration the opacitized margin of the crystal often passes into the dirty aggregates of haematite, and at the same time the crystal changes to haematite along its cracks or cleavages. Hypersthene and augite are more stable minerals than hornblende

but they finally begin to segregate haematite along margins, cracks, and cleavages. Hypersthene under such conditions shows much stronger pleochroism. Some hypersthene and augite are entirely replaced by haematite, as can often be seen in the groundmass of specimens from the summit of the mountain. All the magnetite grains then similarly pass into haematite, giving a dusty appearance to the groundmass. This is also commonly the case with the hornblende in its final alteration stage. During alteration the index of refraction and birefringence gradually increase, but there is a decrease in the extinction-angle.

Origin of the brown hornblende and biotite.

So far as the investigation has gone at present the distribution of brown biotite seems to be restricted to a small area, whereas brown hornblende has been collected by the writer from various parts of Shabō-zan. The occurrence of this hornblende is particularly well shown along the road between Sōzan and Chōhokutō. It may also be expected in the same kind of lava poured out from Shichisei-zan and elsewhere. As will be understood from the gradual transition between the two kinds of andesite, such a brown hornblende-bearing variety is undoubtedly an alteration product from the grey one. It has, of course, not resulted from the alteration due to weathering, as there is no such evidence. It is more reasonable to attribute the reddish-brown colour of the andesite and the occurrence of brown hornblende to the predominance of ferric oxide.

S. Kōzu and his associates[1] have recently studied the relations between the grey andesite and the reddish variety from the volcano Sambé. According to them the volcano Sambé is composed of two similar types of rocks which differ in their hornblendes and biotites. In the first type the hornblende is the common brown variety and the biotite is meroxene; in the second type the hornblende is basaltic and the biotite is meroxene; and in the third type the hornblende is basaltic and the biotite is anomite. Kōzu[2] also concludes that the reddish andesite containing basaltic hornblende and anomitic mica may be produced by the reheating of the grey andesite containing common

[1] S. Kōzu, B. Yoshiki, and K. Kani, Sci. Rep. Tōhoku University, Ser. 3, 1927, vol. 3, p. 143 [Min. Abstr., vol. 3, p. 495].

[2] S. Kōzu, An interesting example of the mode of occurrence of basaltic hornblende associated with anomitic biotite in the quartz-andesite which forms the volcano Sambé, Japan. Proc. 4th Pan-Pacific Science Congress, Java, 1929, vol. 2, B, p. 721 [Min. Abstr., vol. 4, p. 287].

hornblende and meroxene mica at a temperature higher than 750° C. Howel Williams [1] carried out a similar experiment to convert the common hornblende to the brown variety under oxidizing or neutral conditions. He used specimens of the coarsely porphyritic, grey andesite from near the West Marysville Buttes in California and changed them into reddish varieties in which the common hornblende passed into the brown one with small extinction-angle, $\gamma : c = 2°$. He also tried to apply the results of these thermal experiments to the presence of the brown hornblende-bearing andesite from Shabō-zan. Further, many other experimental attempts to convert green hornblende to the brown variety or basaltic type have been made by Rosenbusch, Schneider, Belowsky, Graham, Kunitz, Barnes, and others.[2]

The brown hornblende from Shabō-zan is, however, found in a rather different condition. The writer has examined many specimens of the grey andesite and its noritic inclusions with a fresh appearance, but he has not yet found any trace of green hornblende from which the brown variety might be derived. The gradual transition is, on the other hand, always traceable between basaltic hornblende and the brown variety in slightly altered andesites. It is still more remarkable that the brown hornblende shows a high percentage of TiO_2, which cannot be expected in the green hornblende. Its chemical properties, thus, also seem to prove that it was altered from basaltic hornblende. Both microscopical and chemical evidence suggest that its formation may be the result of oxidation, probably due to reheating. The same explanation may be accepted for the formation of brown biotite.

Summary.

(1) So far as known at present the basaltic hornblende is mostly contained in the grey variety of andesite and its noritic inclusions.

(2) Brown hornblende, on the other hand, predominantly occurs in brown andesite.

(3) The occurrence of the brown biotite is not known in the andesite: it is restricted only to the noritic inclusions.

(4) There are various stages of alteration among these hornblendes, gradually changing the pleochroism.

[1] H. Williams, Geology of the Marysville Buttes, California. Univ. Calif. Publ. Bull. Dept. Geol. Sci., 1929, vol. 18, no. 5, p. 194.

[2] References given by V. E. Barnes, Changes in hornblende at about 800° C. Amer. Min., 1930, vol. 15, pp. 393–417 [Min. Abstr., vol. 4, p. 391].

(5) Both hornblende and biotite show a similar pleochroic scheme in their later stages: hypersthene, augite, and magnetite finally change into haematite during this process.

(6) The hornblende shows an increase in the index of refraction and birefringence, while the extinction-angle decreases gradually. Chemically, the brown hornblende shows a conspicuous decrease in FeO.

(7) Brown hornblende and biotite were derived from basaltic varieties, as shown by various transitions among them. It is evident that the brown hornblende here has not come from a green variety.

(8) The formation of brown hornblende and biotite may be due to the oxidation of basaltic varieties, probably under a certain condition of reheating where FeO passes into Fe_2O_3.

A chemical, optical, and X-ray study of nepheline and kaliophilite.

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(With Plates XXI and XXII.)

[Read January 13, 1931.]

Summary.—Correlated data prove the approximate constancy of the number of oxygen atoms in the unit cells of several nepheline and elaeolite specimens. Thence the number of atoms of each kind per unit cell have been counted. The cell-volumes and optical properties have also been correlated with the chemical composition. An approximate structure is suggested which, together with the chemical work, explains the variable composition of nepheline. The contents of the unit cell may be written Si_{16-n} $Al_n(Na,K,\frac{1}{2}Ca)_n O_{32}$, where n ranges from 6·6 to 8·2. Kaliophilite is shown to possess a much larger cell than that of nepheline, and its Lauegram exhibits higher symmetry. 'Pseudonepheline' (rich in potassium) has a slightly greater cell-volume than normal nepheline, but its Lauegram is almost identical and its axial ratio only slightly less.

Nepheline.

The occurrence of nepheline as well-formed crystals is restricted to comparatively few localities, although as the massive variety elaeolite and more generally as a rock-forming mineral it is very widely distributed. Kaliophilite has been observed only in the ejected blocks from Mt. Vesuvius, Italy. Both minerals possess hexagonal symmetry and are generally represented by the simple formulae $NaAlSiO_4$ and $KAlSiO_4$ respectively, although in the former case it has long been recognized that some potassium is also present and the silica content is more than that indicated by the formula. With one or two exceptions, the careful chemical work that has

already been carried out on nepheline has been directed to obtaining empirical molecular formulae in agreement with the analyses, and the scarcity of correlated chemical and physical data has so far hindered any attempt to relate variations of chemical composition with changes in physical properties.

The present work has been mainly undertaken to correlate changes in refractive index, birefringence, dispersion, density, and unit-cell dimensions of nepheline with changes in chemical composition, and also to trace the physical and chemical relationship between the minerals nepheline and kaliophilite. Nepheline, for which there has been much more material available for study, will first be dealt with. Nine specimens in all were selected from the British Museum collection, including two specimens of elaeolite from different localities. The well-known Monte Somma nephelines are represented by six specimens, these having been chosen in the first place because they showed sensible variations in refractive index and density. The ninth specimen is a nepheline from Capo di Bove near Rome. This probably corresponds to the nepheline first named 'pseudo-nepheline' and is of particular interest owing to the high potassium content.

I. Nepheline, Monte Somma, Mt. Vesuvius, Italy. Large glassy hexagonal prisms enclosing needles of hornblende, on a block containing sanidine, augite, hornblende, idocrase, and wollastonite. This specimen originally belonged to T. Monticelli, whose magnificent collection of Vesuvian minerals and rocks was acquired by the Trustees of the British Museum in 1823. B.M. 59691(24).

II. Nepheline, Monte Somma. Large clear crystals (one having a base-edge of 10 mm., height 7 mm.) associated with hornblende and idocrase on a sanidine block. B.M. 59846.

III. Nepheline, Monte Somma. Small crystals varying in dimensions from the size of a pea to large translucent crystals, one measuring 8 mm. in height, and having a base-edge of 12 mm., in augite-lined cavities of a mica-forsterite block. The crystals enclose flakes of a very pale green biotite. B.M. 59844(3).

IV. Nepheline, Monte Somma. Large, friable, milk-white prisms on a block containing green augite, brown biotite, hornblende, sanidine, and idocrase. The crystals vary from about the size of a pea up to $9 \times 6\frac{1}{2}$ mm. B.M. 51495.

V. Elaeolite, Ilmen Mts., Urals, Russia. This specimen ($5 \times 2\frac{1}{4} \times 2$ cm.) was originally labelled 'cancrinite', but it lacks a perfect prismatic cleavage. The fragment has a faint pink colour and gave sufficient fresh material for chemical and physical work. B.M. 39946.

VI. Nepheline, Monte Somma. Clusters of perfect glassy crystals, varying from 5 to 10 mm. in length, the base-edge being in most cases about one-third the height, with large idocrase crystals on a carpet of augite covering a limestone block. B.M. 51493.

VII. Elaeolite, Larvig, Norway. A green slab ($10 \times 7 \times 4$ cm.) including hornblende and fluorspar. Fragments were taken from the fresh part of the specimen

where the material seemed uniform except for a few white streaks. A well-defined cleavage parallel to $(10\bar{1}0)$ was observed when preparing wedges for refractive index work. B.M. 94659.

VIII. Nepheline, Monte Somma. Glassy, translucent prisms about 1 cm. in height and $\frac{1}{2}$ cm. across base, enclosing green biotite and associated with idocrase and hornblende on a large biotite-augite block. B.M. 40607.

IX. 'Pseudonepheline', Capo di Bove, Rome, Italy. This specimen consists of prismatic plates and skeletal crystals covering a slab of leucite-tephrite. The crystals vary from 0·5 to 3 mm. across the base and frequently contain a hornblende inclusion which distorts the crystal. B.M. 14285, acquired from H. Heuland in 1840. H. Traube [24] found needles of kaliophilite upon specimens from Capo di Bove, but I have failed to detect this association.

The preliminary measurements of the refractive index and density that were made on the Monte Somma specimens are given below. The refractive index was measured by the Becke line method, and the density by floating in heavy liquids with known indicators. The specimens are arranged in the order described above.

No.	Density.	Refractive indices.	
	d.	ω.	ϵ.
I.	2·61	>1·530	<1·530
II.	2·63	1·535	>1·530
III.	2·60	<1·535	1·530
IV.	2·59	1·530	<1·530
VI.	2·61	>1·535	<1·535
VIII.	2·58	>1·535	>1·535

Crystals were carefully selected from each specimen and where sanidine was intimately associated with the nepheline the crystals were separated by placing in a mixture of bromoform and benzene in which sanidine just floated. Suitable material, free from inclusions where possible, was then set aside for physical measurements, and the remaining crystals finely powdered. Two separations with bromoform and benzene were used for the nephelines associated both with sanidine and heavier minerals, such as mica, hornblende, or augite. Finally, small samples from each specimen after separation were examined under the microscope for any foreign materials. Fresh fragments of the elaeolites were similarly selected and material for study picked by hand. The powdered material was then handed over to Mr. M. H. Hey for chemical analysis.

Chemical Analyses (by M. H. Hey).

Owing to the care taken in selecting material the amount available for analysis after bromoform separations was less than 0·25 gram, for analyses I, II, and IV, and only 0·0641 gram for analysis IX.

The results are given in Table 1, and the molecular ratios calculated therefrom are given in Table 2. The specimens are arranged from nos. I to IX in order of increasing potassium content; nos. VIII and IX are relatively silica-rich and silica-poor respectively. Colorimetric estimates of the silica to alumina ratios were also made on these two specimens and found to be in substantial agreement with the analyses.

Table 1. *Chemical analyses of nepheline.*

(By M. H. Hey.)

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO_2 ...	44·08	44·79	44·07	43·55	43·40	42·20	44·09	48·53	40·2
Al_2O_3 ...	34·71	34·84	34·03	34·66	33·31	34·60	32·78	29·18	36·0
Fe_2O_3 ...	—	—	—	—	—	—	0·31	—	—
MgO ...	—	—	—	0·05	0·03	0·04	0·01	—	—
CaO ...	2·51	1·91	1·92	4·44	1·20	2·14	1·45	2·44	3·7
Na_2O ...	16·46	15·40	14·00	12·09	15·96	14·77	14·60	11·92	13·8
K_2O ...	3·17	4·06	4·82	4·87	5·09	5·22	5·66	7·53	8·7
H_2O+ } ...	0·45	0·10	0·80	0·25	0·61	0·60	0·82 }	0·35	nil
H_2O- }			0·25	0·25	0·16	0·23	0·16 }		
Total ...	101·38	101·10	99·89	100·16	99·76	99·80	99·88	99·95	102·4
% oxygen...	44·90	45·03	45·01	44·89	44·59	44·54	44·70	44·81	44·55

Table 2. *Molecular ratios and number of atoms per unit cell (calculated from Tables* 1 *and* 3).

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO_2 ...	0·7337	0·7455	0·7335	0·7249	0·7224	0·7024	0·7339	0·8078	0·669
Al_2O_3 ...	0·6810	0·6836	0·6677	0·6800	0·6535	0·6788	0·6431	0·5725	0·710
Fe_2O_3 ...	—	—	—	—	—	—	0.0039	—	—
MgO ...	—	—	—	0·0012	0·0007	0·0010	0·0002	—	—
CaO ...	0·0448	0·0341	0·0342	0·0792	0·0214	0·0382	0·0259	0·0435	0·066
Na_2O ...	0·5310	0·4968	0·4516	0·3900	0·5148	0·4765	0·4710	0·3845	0·445
K_2O ...	0·0673	0·0862	0·1023	0·1034	0·1081	0·1108	0·1202	0·1599	0·185
H_2O+ }	0·0500 }	0·0111 }	0·0888	0·0278	0·0677	0·0666	0·0910 }	0·0389 }	nil
H_2O- }			0·0278	0·0278	0·0178	0·0255	0·0178 }		
Si ...	8·29	8·39	8·44	8·30	8·38	8·16	8·53	9·27	7·7
Al ...	7·69	7·70	7·69	7·78	7·58	7·89	7·47	6·57	8·1
Ca ...	0·51	0·38	0·39	0·91	0·25	0·44	0·30	0·50	0·8
Na ...	6.00	5·59	5·20	4·46	5·97	5·53	5·47	4·41	5·1
K ...	0·76	0·97	1·18	1·18	1·25	1·29	1·40	1·83	2·1
Si+Al...	15·98	16·09	16·13	16·08	15·96	16·05	16·00	15·84	15·8
ΣR ...	7·77	7·33	7·17	7·46	7·72	7·71	7·47	7·24	8·8

Hitherto, attempts to associate a molecular formula with every mineral have resulted in a large number of careful analyses on

picked material. Recent work depending to some extent upon the results of X-ray investigations has, however, modified the goal of the mineralogical chemist. His attention is not now solely focused upon the molecule, but upon the unit cell; chemical analyses of minerals are no longer stretched beyond their elastic limits to fit the formula for a hypothetical molecule; they are more rightly utilized to obtain the number of atoms in the unit cell.

In order to proceed from the molecular ratios given in Table 2 to counting the atoms in the unit cell for each specimen analysed we must measure the densities and the cell-sides of the crystals set aside for physical work.

Density measurements.

The density of each sample of nepheline and elaeolite was measured by a flotation method. A small thermometer which could be totally immersed in a small vertical tube containing a mixture of bromoform and benzene was weighed first in air and then in toluene whose density at a known temperature had been previously determined by the pyknometer method. Each crystal or fragment was then carefully balanced in the tube of bromoform and benzene by adding sufficient of one or other of the two liquids and well shaking the corked tube. The small thermometer was then weighed in the liquid, the temperature noted, and the liquid again shaken thoroughly. The crystal remained in the liquid throughout the measurement so that it was known whether the density of the liquid had increased during the weighing operations. Until experience has been gained, the operation of balancing the crystal has to be repeated a few times until allowance can be made for the amount of benzene which evaporates during weighing. Sufficient material from the green elaeolite no. VII was available to obtain a pyknometer reading of its density. This measurement carried out by Mr. Hey is in good agreement with the result I obtained for a fragment by the flotation method. The densities obtained by the above method are given in Table 3.

X-ray measurements of the cell-sides of nepheline.

For the purpose of obtaining accurate cell-side measurements of a and c, those crystals were first chosen which showed good m and c faces. The presence of the latter allowed the setting up of the crystal by optical means so that an a-axis was exactly vertical. For

this purpose the X-ray spectrometer was used as a goniometer with an ordinary light source. By oscillating the crystal through an angle of 5° for certain azimuths, X-ray diffractions with parallel-jawed slits could be obtained on a flat plate at a known distance from the axis of oscillation, corresponding to (0004) and $(40\bar{4}0)$ respectively. At a plate distance of 4 cm., and taking care not to over-expose the plate, the Cu-$K_{\alpha 1}$ ($\lambda = 1{\cdot}537$ Å.) and the Cu-$K_{\alpha 2}$ ($\lambda = 1{\cdot}541$ Å.) diffractions were readily resolved, and in addition the Cu-K_{β} ($\lambda = 1{\cdot}389$ Å.) and W-$L_{\alpha 1}$ ($\lambda = 1{\cdot}473$ Å.) diffractions were also observed. The calculated spacings from these different wave-lengths agree very closely. In one case the diffractions (0002) and $(20\bar{2}0)$ were obtained at two different plate distances on the same plate. These also confirmed previous measurements on the same crystal and confirmed the value of the distance of the plate to the axis of oscillation. The accuracy of such spacing measurements from one crystal to another is ± 0.01 Å. for a cell-side of about 10 Å. The majority of the nepheline crystals were studied in this way. The elaeolite specimens were roughly oriented by observing the direction of the optic axis under the microscope. One or at the most two Laue photographs of short exposure were then sufficient to adjust the specimens for oscillation about the *a*- or *c*-axes. In this case the slits did not provide good diffractions, and accordingly the usual rotation photographs were taken with very small splinters of the specimens. The variations in the spacings calculated from the layer-lines due to crystal size were in this way minimized, but the cell-sides for elaeolite can be relied upon only to $\pm 0{\cdot}02$ Å. The cell-sides thus measured are given in Table 3.

Table 3. *Physical data for nepheline specimens.*

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Density (D_{15}^{15}) ...	2·614	2·620	2·616	2·576	2·629	2·608	2·597*	2·591	2·64
ω	1·5341	1·5385	1·5355	1·5299	1·5391	1·5390	1·5394	1·5403	1·540
ϵ	1·5301	1·5349	1·5322	1·5266	—	1·5355	1·5360	1·5371	1·54
$\omega - \epsilon$	0·0040	0·0036	0·0033	0·0033	—	0·0035	0·0034	0·0032	0·00
Cell-edge *a* ...	9·975	9·95	9·96	9·94	9·96	9·96	9·97	9·985	9·99
Cell-edge *c* ...	8·33	8·36	8·34	8·31	8·36	8·345	8·37	8·35	8·38
c/*a*	0·835	0·840	0·837	0·836	0·839	0·838	0·840	0·837	0·83
Axial ratio† ...	0·835	0·838	0·834	—	—	0·8385	—	0·837	—
a^2c Å.^{3}	827	827	827	821·5	829	829	832	833	837
Number of O atoms per unit cell.	31·9	32·0	32·0	31·1	31·9	31·6	31·6	31·7	32·4

* Mr. Hey's pyknometer figure for this elaeolite is $D_{15}^{15} = 2{\cdot}5965$.

† Axial ratio determined goniometrically.

Counting the number of atoms per unit cell.

It is now possible to calculate from the physical and chemical data the number of atoms in the unit cell of each specimen and thence to discuss the analyses more adequately than was possible merely from a consideration of the molecular ratios. The measured cell-sides and densities for each specimen have been given in Table 3. From the former measurements one proceeds to calculate the values of a^2c, the volume of the rhomb-based cell being $(\sqrt{3}/2)\,a^2c$. From these volumes and the measured densities may be calculated the molecular weights of the unit-cell contents and thence from the oxygen percentage figures given in Table 1 the number of oxygen atoms per unit cell. The expression for this number is $[(x/16)d.\,(\sqrt{3}/2).a^2c]/1{\cdot}65$, where x is the oxygen percentage directly obtained from chemical analysis, d is the density, and 1·65 is the factor corresponding to the mass of a hydrogen atom. The tabulated values for the number of oxygen atoms can be seen to approximate to 32 with a maximum variation, excepting no. IV, of $2\frac{1}{2}$ %. This agreement is very good considering that the calculation is influenced by errors in no less than three measurements, viz. chemical analysis, density, and X-ray work. This result constitutes perhaps extra evidence in favour of W. L. Bragg's [60] underlying assumption in his structural work on the silicates, namely that no matter what variations are found to exist in the chemical composition of a naturally occurring mineral, the unit cell will be found to contain an integral number of oxygen atoms, that number being characteristic of each structure type. From the work of Gossner,[51] Gottfried,[52] Jaeger,[50] and Schiebold [56] it was of course to be expected that the number of atoms of oxygen in the unit cell of nepheline would be 32. Once this number is known the count of all the other atoms in the unit cell can be carried out simply from the chemical analyses, providing that the material analysed is pure nepheline. In the present instance, knowing the chemical composition of each nepheline studied in Table 1 we can then count the number of atoms of Si, Al, Na, K, and Ca per unit cell (Table 2). Mr. M. H. Hey is of opinion that, so far as his analyses are concerned, the iron and water content, if any, are not combined with the nepheline, but are present as impurity. A count of the atoms shows that the number of Si atoms varies from one nepheline to another, and is, with the possible exception of no. IX, generally greater than the number of aluminium atoms present. This is, of

course, equally apparent from a consideration of the molecular ratios in Table 2. The sum of Si and Al atoms in each case, however, is approximately the same and equals 16. This is a remarkable fact, and suggests at once an explanation of the excess silica usually found in nepheline analyses.

It is interesting now to proceed to recalculate the large number of nepheline analyses already in existence assuming in each case that the unit cell contains 32 oxygen atoms. The sum of the Al and Si atoms always lies very close to 16, not only for modern analyses, such as those of Morozewicz,[53] but also for the older ones (see Table 4). From valency considerations, if the sum of the silicon and aluminium atoms equals one-half the number of oxygen atoms in the unit cell, then the sum $2Ca + K + Na = \Sigma R$ must also equal the number of aluminium atoms per unit cell. The following simple calculation makes this clear. Let the number of Si atoms be $16 - n$, Al atoms n, Na atoms x, K atoms y, and Ca atoms z. The number of oxygen atoms associated with a monovalent term is $\frac{1}{2}$, a divalent term 1, &c., so that $2(16 - n) + 3n/2 + x/2 + y/2 + z = 32$ = total no. of oxygen atoms per unit cell. Therefore $x + y + 2z = n$. Furthermore, it can be shown that the difference $(2Ca + K + Na) - Al$ is four times the difference $(Si + Al) - 16$. Hence we have a more sensitive indicator in the former expression of whether the sum of silicon and aluminium atoms equals 16 for all the recalculated analyses. For Mr. Hey's analyses the mean value of $(2Ca + K + Na) - Al = 0{\cdot}01$, i.e. $Si + Al = 15{\cdot}995$. For about a hundred previous analyses the mean values are respectively 0·02 and 15·995.

Variation in the chemical composition of nepheline.

If the number of Si atoms be plotted as abscissae and the number of Al atoms as ordinates a straight line is obtained sloping down to the right (fig. 1). The sum of the atoms $2Ca + K + Na$ should also fall on this line in each case. Now if the Na, K, and Ca atoms each be plotted separately as ordinates we should be able to trace whether the variation of Na, K, or Ca content of nepheline is connected in any way with the silicon content. For Mr. Hey's analyses there is a well-defined minimum shown by the potassium curve corresponding to about 8·4 atoms of silicon and 1·2 atoms of potassium per unit cell. If the same plot be carried out for the recalculated analyses then a similar result is obtained, the minimum corresponding to 1·25 atoms of potassium and 8·45 atoms of silicon. The variation in

Table 4. The number of atoms per unit cell calculated from previous analyses of nepheline.

Literature No.	Si.	Al.	Mg.	Ca.	Na.	K.	Si+Al.	ΣR.
1	8·42	7·59	—	—	7·57	—	16·00	7·57
2	8·15	7·81	0·13	0·10	6·07	1·46	15·96	7·79
,,	8·37	7·65	0·23	0·04	5·35	1·70	16·02	7·59
3	8·66	7·36	—	0·06	5·90	1·26	16·02	7·28
,,	8·65	7·35	—	0·05	5·94	1·30	16·00	7·34
,,	8·65	7·34	—	0·07	5·90	1·33	15·99	7·37
,,	8·64	7·38	—	0·07	5·74	1·44	16·02	7·32
,,	8·60	7·47	—	0·16	5·81	1·08	16·07	7·21
,,	8·76	7·25	—	—	5·99	1·23	16·01	7·22
,,	8·43	7·59	0·02	0·07	5·91	1·41	16·02	7·50
,,	8·50	7·53	—	0·05	5·87	1·40	16·04	7·37
,,	8·47	7·50	—	0·36	5·72	1·20	15·97	7·64
,,	8·52	7·49	—	0·37	5·56	1·16	16·01	7·46
,,	8·35	7·61	—	0·41	5·85	1·09	15·96	7·76
,,	8·51	7·42	—	0·17	5·97	1·39	15·93	7·70
4	8·44	7·39	0·032	0·74	5·31	1 24	15·83	8·09
5	8·47	7·37	0·04	0·06	6·12	1·77	15·84	8·09
6	8·52	7·43	—	0·08	6·12	1·35	15·95	7·63
7	8·78	7·12	0·16	0·18	5·66	1·23	15·90	7·57
8	9·03	6·94	—	0·22	4·97	1·66	15·97	7·07
9	8·59	7·47	—	—	6·03	1·23	16·06	7·26
10	8·45	7·77	—	0·10	5·61	1·08	16·22	6·89
,,	8·49	7·67	—	0·11	5·65	1·18	16·16	7·05
,,	8·46	7·69	—	0·14	5·63	1·19	16·15	7·10
,,	8·57	7·58	—	—	5·95	1·03	16·15	6·98
12	8·39	7·56	0·07	0·32	5·77	1·20	15·95	7·75
,,	8·43	7·48	0·04	0·36	5·95	1·10	15·91	7·85
,,	8·44	7·45	0·06	0·27	6·06	1·18	15·89	7·90
13	8·53	7·58	0·03	0·08	5·80	1·08	16·11	7·10
14	9·00	6·92	—	—	5·51	1·73	15·92	7·24
15	8·50	7·39	—	0·10	6·33	1·25	15·89	7·78
16	8·46	7·42	—	0·15	6·24	1·39	15·88	7·93
,,	8·22	7·85	—	0·10	5·72	1·67	16·07	7·59
17	8·33	7·62	—	0·31	6·96	0·22	15·95	7·80
18	8·36	7·77	—	—	6·16	1·11	16·13	7·26
22	8·70	7·40	0·05	0·41	4·69	1·40	16·10	7·01
23	8·35	7·64	—	0·03	6·30	1·32	15·99	7·68
25	8·51	7·54	—	0·09	5·81	1·34	16·05	7·33
26	8·34	7·70	0·03	0·52	5·38	1·12	16·04	7·60
27	8·91	7·12	—	0·07	5·49	1·39	16·03	7·02
28	8·66	7·41	—	—	6·00	1·12	16·07	7·12
29	8·29	7·61	0·02	0·42	5·74	1·42	15·90	8·04
,,	8·20	7·76	0·02	0·40	5·62	1·46	15·96	7·92
,,	8·31	7·62	0·05	0·44	5·84	1·08	15·93	7·90
,,	8·31	7·61	0·08	0·46	5·80	1·04	15·92	7·92
,,	8·42	7·57	—	0·10	6·00	1·42	15·99	7·62

Table 4—continued.

Literature No.	Si.	Al.	Mg.	Ca.	Na.	K.	Si+Al.	ΣR.
29	8·47	7·54	—	0·11	5·92	1·39	16·01	7·53
,,	8·45	7·54	—	0·06	6·11	1·36	15·99	7·59
,,	8·47	7·52	—	0·06	6·05	1·39	15·99	7·56
,,	8·45	7·54	—	0·05	6·02	1·48	15·99	7·60
,,	8·44	7·53	—	0·06	6·01	1·53	15·97	7·66
,,	8·36	7·63	—	0·07	6·10	1·44	15·99	7·68
,,	8·36	7·63	—	0·07	6·10	1·43	15·99	7·67
30	8·17	8·13	—	—	6·13	0·78	16·30	6·91
31	8·60	7·37	0·02	0·06	6·38	0·98	15·97	7·52
32	7·99	7·80	—	0·55	4·95	2·57	15·79	8·61
33	8·52	7·54	—	—	5·95	1·33	16·06	7·28
34	8·44	7·68	—	0·19	5·04	1·77	16·12	7·19
35	8·51	7·49	—	—	6·14	1·37	16·00	7·51
,,	8·52	7·49	—	—	6·08	1·38	16·01	7·46
,,	8·59	7·43	—	—	6·00	1·37	16·02	7·37
36	8·24	7·64	—	0·22	6·35	1·33	15·88	8·12
,,	8·41	7·57	—	0·19	6·22	1·04	15·98	7·64
39	8·33	7·57	—	0·12	6·32	1·44	15·90	8·00
,,	8·37	7·62	—	0·09	6·08	1·42	15·99	7·68
,,	8·36	7·66	—	0·06	6·08	1·38	16·02	7·58
,,	8·33	7·60	—	0·07	6·34	1·47	15·93	7·94
40	8·44	7·36	—	0·01	6·37	1·04	16·07*	7·43
41	8·42	7·65	—	0·18	6·12	0·86	16·07	7·34
42	8·28	7·70	—	0·45	5·46	1·42	15·98	7·78
45	8·10	8·10	—	0·13	5·48	1·55	16·20	7·29
46	8·18	8·11	—	0·01	5·54	1·41	16·29	6·97
53	8·34	7·60	—	0·06	6·13	1·55	15·94	7·80
,,	8·37	7·74	—	0·02	5·99	1·32	16·11	7·35
,,	8·46	7·50	—	0·03	6·02	1·60	15·96	7·68
				Altered nephelines.				
31	8·67	7·61	0·02	0·05	5·62	0·76	16·28	6·52
,,	8·66	7·86	0·02	0·05	5·16	0·52	16·52	5·82

* No. 40 contains 0·58 atoms of beryllium counted in with the silicon and aluminium.

calcium content would also appear to follow the potassium curve, with a minimum at about 0·35 atoms of calcium and 8·5 atoms of silicon for Mr. Hey's analyses. There is one notable exception on this curve, however, namely no. IV, which has a very high calcium content of 0·906 atoms, and a silicon content of 8·297 atoms per unit cell. The conclusions that may be safely drawn then are:

(*a*) Naturally occurring nephelines always contain some potassium which is never less than 1 atom per unit cell For nephelines with greater or less silica content than 8·4 atoms the potassium content

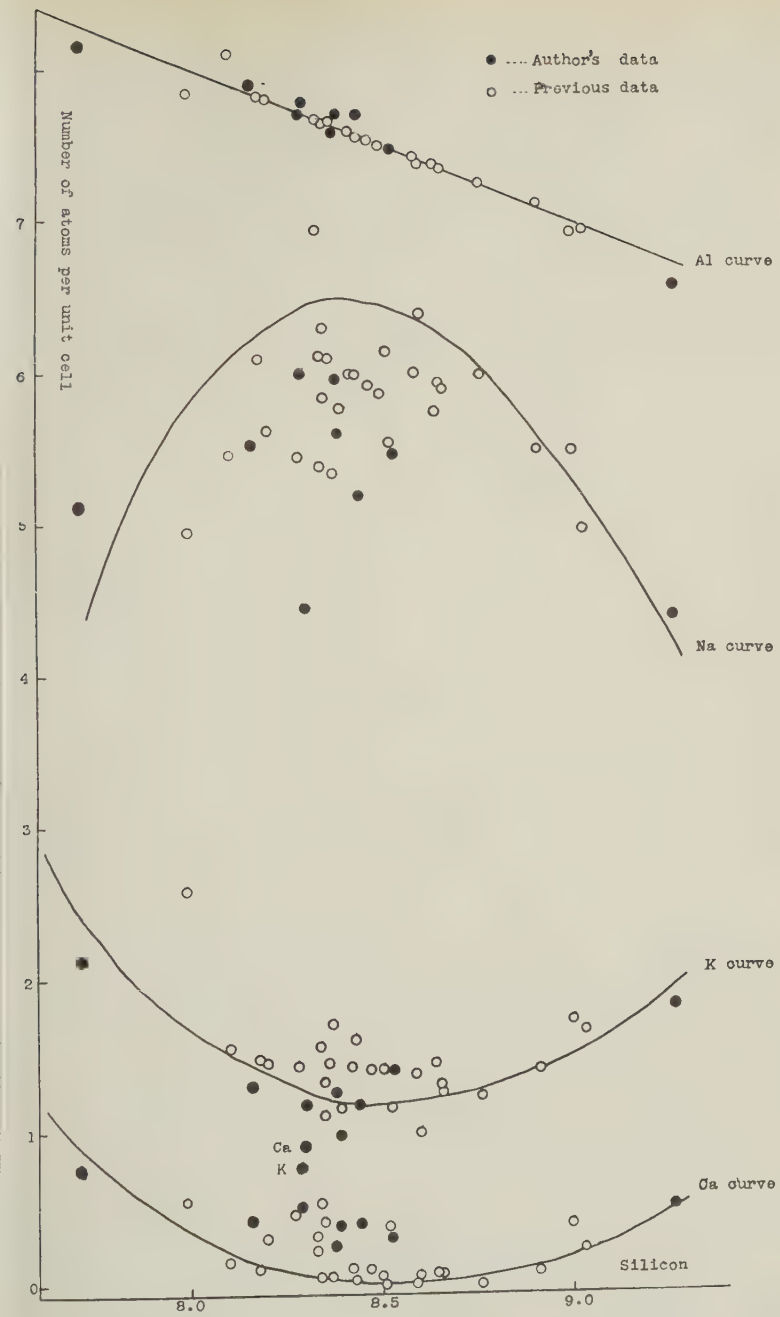

FIG. 1. Graphs plotting number of silicon atoms per unit cell of nepheline against number of aluminium, sodium, potassium, and calcium atoms per unit cell.

increases on both sides of the minimum to about 2 atoms per unit cell. There is no evidence to show, however, that this is a maximum content.

(*b*) The calcium content fluctuates more irregularly, but with one exception also shows a curve with a minimum.

(*c*) Mr. Hey [59] has concluded for the zeolites that the Si to Al ratio in the parent-magma is the controlling factor in the composition of the resulting zeolite. In the present case the potassium and calcium contents appear to be distinct factors of equal importance.

Morozewicz [53] has deduced from a large number of careful analyses of nepheline and elaeolite that the ratio of the K to Na content remains sensibly constant, although this ratio for the parent-rock exhibits considerable variations. The present work shows that this conclusion cannot be applied to all nephelines; in fact the variation of Na to K is represented more accurately by the curves in fig. 1. One final consideration of fig. 1 is of interest. The maximum in the sodium curve lies at about 8·4 atoms of silicon and 6·2 atoms of sodium. It is noteworthy that the two pronouncedly sodium-rich nephelines, no. 1 and no. 17 of Table 4, approach an 8·4 silicon atom content. This leads to the speculation as to whether the artificial nephelines so far studied have corresponded to this composition rather than the ideal $NaAlSiO_4$. If we take Bowen's [37] density figure, 2·619, for artificial nepheline and plot it with the density data and also the cell-volume data, we shall see that his figure agrees far more closely with existing mineralogical data when we assume 8·4 atoms of silicon rather than eight. (See figs. 2 and 3.)

Warren [57] has recalculated amphibole analyses on a basis of an integral number of oxygen atoms and hydroxyl groups per unit cell and has shown that chemical analyses formerly thought to be misleading are actually in closer agreement with the crystal-structure of amphiboles determined by X-ray work than the idealized formulae. The present work indicates that the majority of nepheline analyses recalculated to give the number of atoms per unit cell show a surprisingly constant number for the Si + Al content. The contents of the unit cell of nepheline may in fact be written $Si_{16-n}Al_n(Na, K, \frac{1}{2}Ca)_n O_{32}$. In this connexion Mr. Hey has suggested a new method for assessing the value of chemical analyses. If a chemical analysis sums to a figure lying between 99·7 and 100·8 it is considered a first-class analysis. If in the present case the sum of Si and Al atoms recalculated from such an analysis also lies between 15·9 and

16·1 then we may consider that a first-class analysis has been performed on first-class material, namely, fresh nepheline free from impurities. The second criterion of the Si and Al atoms summing to 16 is thus another important check on chemical analysis. It is obvious that such a principle is of general application and Mr. Hey will no doubt develop the idea more fully in connexion with his work on zeolites.

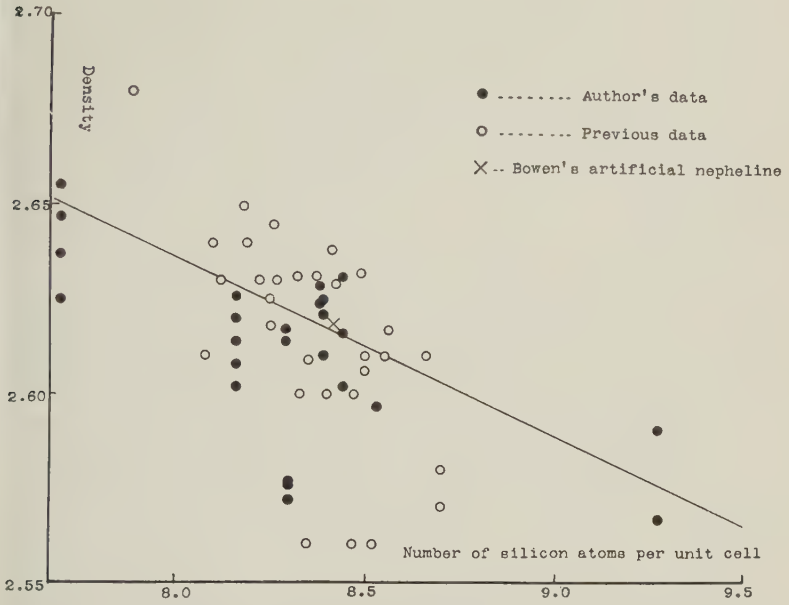

Fig. 2. Graph plotting the number of silicon atoms per unit cell against the density of nepheline. Series of points falling on the same ordinate give the density of individual crystals taken from each analysed specimen.

The correlation of density and the number of silicon atoms per unit cell.

The density data may now be used to correlate the variation of density with chemical composition. The measurements were of course carried out on more than one crystal from each specimen and the additional data used for the purposes of correlation are shown in Table 6. By plotting (fig. 2) the values obtained for each crystal it is found that a small decrease of density of 0·01 to 0·02 accompanies the increase of silicon by one atom per unit cell. From Table 5 the

density of nepheline and its silicon content are also plotted for the correlated data of previous workers. The plotted values tend to lie about a straight line and the exceptions are probably to be attributed to errors in the density figure due to inclusions or flaws full of air. For water-clear crystals the errors of measurement are a minimum and the data for these follow the straight line relation more closely.

The correlation of cell-volume and the number of potassium atoms per unit cell.

It has not been possible to trace any relationship between the lengths of the cell-edges and the chemical composition, but if the cell-volumes $(\sqrt{3}/2)\,a^2c$ be considered there is a very small but definite increase with potassium content (Table 3 and fig. 3). Thus nepheline from Capo di Bove with the highest potassium content has the largest cell.

Reference will shortly be made to the variation in the refractive index of nepheline crystals taken from one and the same specimen. This has rendered the correlation of refractive index with chemical composition very difficult. It may justly be assumed that different crystals from the same matrix possessing different refractive indices are also different in chemical composition. Therefore the relation that has been deduced between cell-volume and the potassium content must be treated with reserve unless further evidence can be adduced. There are, as a matter of fact, three checks on the above results:

(*a*) No appreciable difference can be detected in spacings of nepheline crystals from the same specimen.

(*b*) The cell-volumes calculated from the chemical analyses and each density figure obtained show similar increase of cell-volume with potassium content. The increase in cell-volume per 1 K atom is 13·4 Å^3.

(*c*) Although previous chemical analyses of nepheline are seldom accompanied by complete physical data, density figures are often given (Table 5). Each of these analyses has already been recalculated (p. 576) so that the number of atoms in the unit cell is known (Table 4).

From the density figure and the atomic contents the volume of the unit cell may therefore be calculated (Table 5). It is of interest first to compare the range of volumes thus obtained. The calculated

a^2c values for forty analyses accompanied by density data range from 822 to 852 Å^3. For Hey's analyses calculated values of a^2c range from 824 to 846 Å^3. X-ray measurements yield a range 821·5 to 837 Å^3. The inaccuracy of the density data in a large number of

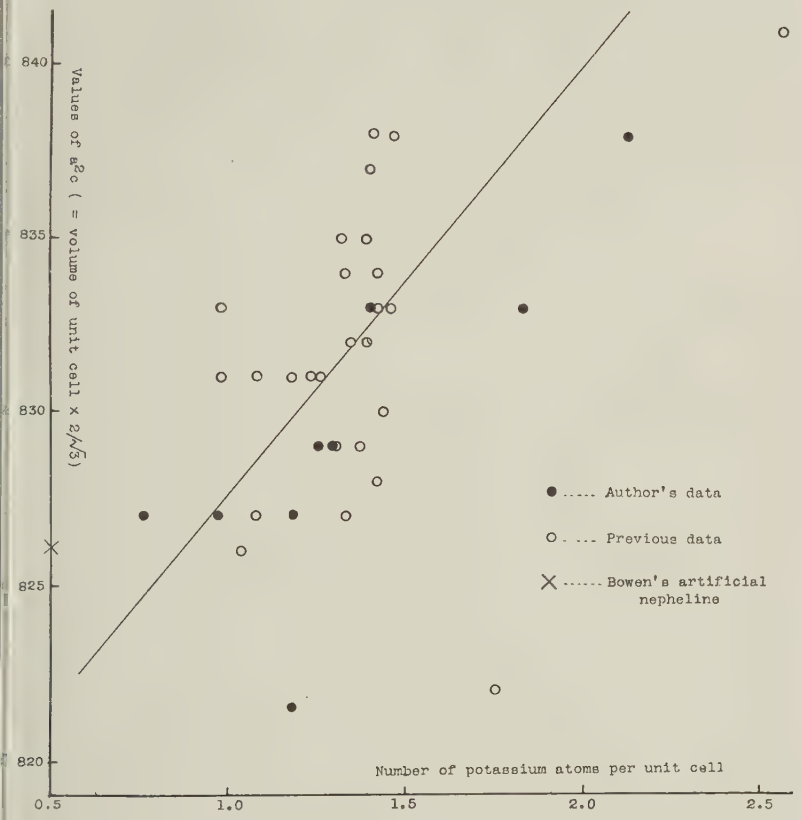

Fig. 3. Graph plotting the number of potassium atoms per unit cell against the cell-volume $\times 2/\sqrt{3}$. (Only the author's data, represented as black spots, were obtained directly by X-ray methods.)

cases prevents the use of older analyses for correlating potassium content with cell-volume. However, there is a definite grouping of the points in fig. 3 about the straight line obtained from direct measurement of a^2c. Anticipating a conclusion that the axial ratio of nepheline probably lies between the limits 0·837 to 0·841, it is

Table 5. Cell dimensions calculated from previous chemical analyses of nepheline accompanied by density data.

Litera-ture No.	Density, *d*.	No. of Si atoms.	Mass of unit cell.	a^2c.	No. of K atoms.	Litera-ture No.	Density, *d*.	No. of Si atoms.	Mass of unit cell.	a^2c.	No. of K atoms.
3	2·617	8·66	1141	831 Å.^{3}	1·26	29	2·640	8·20	1154	833 Å.^{3}	1·46
,,	2·617	8·65	1139	829	1·30	,,	2·640	8·31	1146	827	1·08
,,	2·610	8·65	1143	834	1·33	,,	2·640	8·31	1145	826	1·04
,,	2·610	8·64	1144	835	1·44	,,	2·631	8·42	1150	833	1·42
,,	2·610	8·60	1133	827	1·08	,,	2·631	8·47	1147	832	1·39
,,	2·610	8·76	1139	831	1·23	,,	2·6453	8·36	1152	830	1·44
,,	2·600	8·43	1147	838	1·41	31	2·606	8·60	1139	833	0·98
,,	2·600	8·50	1146	838	1·40	32	2·680	7·99	1183	841	2·57
,,	2·560	8·47	1141	849	1·20	35	2·635	8·51	1148	832	1·37
,,	2·560	8·52	1142	850	1·16	,,	2·635	8·52	1148	832	1·38
,,	2·560	8·35	1145	852	1·09	,,	2·635	8·59	1145	829	1·37
6	2·629	8·52	1148	832	1·35	39	2·6295	8·32	1157	838	1·44
10	2·600	8·45	1134	831	1·08	,,	2·6295	8·37	1151	834	1·42
,,	to	8·49	1137	831	1·18	,,	2·6295	8·36	1149	832	1·38
,,		8·46	1138	831	1·19	,,	2·6295	8·33	1157	838	1·47
,,	2·6087	8·57	1135	831	1·03	40	2·60	8·44	1129	827	1·04
16	2·600	8·46	1155	847	1·39	42	2·650	8·28	1151	828	1·42
,,	2·630	8·22	1156	837	1·67	45	2·664	8·10	1149	822	1·55
22	2·575	8·70	1135	838	1·40	53	2·625	8·37	1146	832	1·32
23	2·621	8·35	1150	835	1·32	,,	2·628	8·46	1154	837	1·60
29	2·640	8·29	1154	833	1·42						

possible to calculate the probable range in variation of a and c for the recalculated analyses. Assuming a mean value of 0·839 for c/a, it is found that a ranges from 9·93 to 10·05 Å., and c ranges from 8·33 to 8·43 Å. The X-ray measurements of the nephelines I have studied give $a = 9{\cdot}94$ to 9·99 Å., and $c = 8{\cdot}31$ to 8·38 Å. Existing X-ray data are not in complete agreement with these results. The following lower and higher figures have been quoted for Monte Somma nepheline:

	Cell-sides.			
	a.	*c*.	*c/a*.	*Density*.
B. Gossner [51] ...	10·05	8·43 A.	0·8388	2·64
C. Gottfried [52] ...	10·09	8·49	0·8414	2·60
F. M. Jaeger [50] ...	9·87	8·38	0·849	—
E. Schiebold [56] ...	10·1	8·51	0·8426	2·65

Schiebold's figures for nepheline seem to be too high. He has examined material analysed by F. Stella Starrabba.[42] Table 5, no. 42, shows that a^2c calculated from chemical analysis and density is 828·0 Å.^{3}, whereas Schiebold's measured a^2c value = 868·0 Å.^{3}.

Crystallographic measurements.

The direct measurements of the cell-sides also yield values of the axial ratio for each specimen of nepheline (Table 3), and it is interesting to see how they complete the values obtainable by direct measurement with the goniometer. The Monte Somma nepheline specimens generally yield well-developed crystals suitable for goniometric measurement and for deducing directly the axial ratio. In particular nos. VI and II provide crystals rich in faces all of which give single bright reflections. Crystals from the latter specimen show not only the common forms $m\,(10\bar{1}0)$, $c\,(0001)$, p $(10\bar{1}1)$, but also $q\,(10\bar{1}2)$, whilst the former specimen is studded with numerous perfect hexagonal prisms exhibiting $m\,(10\bar{1}0)$, $c\,(0001)$, $p\,(10\bar{1}1)$, $z\,(20\bar{2}1)$, $a\,(11\bar{2}0)$, $s\,(11\bar{2}1)$ all well developed, and $x\,(40\bar{4}1)$ and $t\,(20\bar{2}3)$ as small facets giving weak reflections. For those crystals capable of accurate measurement the axial ratio was calculated from all the possible pyramidal reflections p, z, q, &c. Large crystals vary much more in habit than do the small ones just described. The large prism already referred to under the description of specimen no. II shows very unequal development at its two ends. At one end p is well developed, but it cannot be observed at the bottom end of the crystal. Again, s is present as a large face, much larger than is usual, and quite predominating over the primary pyramid p. Under the conditions of slow growth, which we may assume accompanied the formation of this unusually large nepheline crystal, any change in composition of the mother-liquor or of the physical conditions would have every chance of affecting the relative rates of facial growth and therefore of the relative sizes of the faces. The unequal development of the pyramid-faces for the two ends of this crystal are probably to be referred to the polar nature of nepheline as exhibited by etch-figures and its pyro- and piezo-electric effects (see below). The small glassy nepheline crystals sometimes give only a very faint pyramid reflection due to the poor development of p; but the milk-white crystals, whether large or small, observed particularly on no. IV specimen, fall into an entirely different class and are unsatisfactory for goniometric measurement.

These milky crystals recall the fact that the name nepheline was conferred by Haüy on this mineral because the crystals lose their transparency and become cloudy when immersed in acid. The action of acid is to break up the surface layers and penetrate flaws,

producing colloidal silica. It is conceivable that acid vapours produced during volcanic activity might readily attack nepheline crystals already formed and give rise to the cloudiness so typical of certain specimens. The corrosion would, of course, produce the greatest effect on the forms with high rate of growth. Thus the *p* faces which are always small would tend to disappear completely or become by far the most etched. This is exactly what is found in the milk-white crystals of no. IV. In attempting to obtain an axial ratio determination a number of crystals were minutely examined for *p* faces, but in most cases these were either absent or convex in shape. The *c* and *m* faces also showed signs of corrosion and gave numerous imperfect images. The flaws produced by corrosion undoubtedly contain air and also render the crystals friable; it is probable that the low density value for no. IV may thus be explained.

The remaining specimens, not from Monte Somma, yielded very poor material for work with the goniometer. The 'pseudonepheline' crystals are badly etched, and the *p* planes, when present, are very small. The crystals are frequently distorted by hornblende inclusions, and the angle *cm* sometimes differs from 90° by nearly $\frac{1}{2}$ degree. The values for axial ratio as deduced from interfacial angles are given in Table 3 for five Monte Somma nepheline specimens; the sixth (no. IV) yields an approximate value only, owing to the presence of vicinal faces on *c* and *m*. Crystallographic values are of course lacking for the elaeolites; for these we have to rely upon X-ray measurements, and it is an important point that such determinations are not affected by the presence of vicinal faces nor prevented by the absence of pyramidal forms.

Numerous crystallographic measurements for nepheline are to be found in the literature, but it is only comparatively recently that such data have been published on analysed material. Confusion has also resulted from the fact that the interfacial angles for davyne are almost identical. Many of the early measurements given for nepheline undoubtedly refer to davyne. O. Mügge [49] states that even the classical measurements ($a:c = 1:0{\cdot}838926$) of N. I. Koksharov (1884) were made on the latter mineral. H. Baumhauer's [21] etching experiments, however, were certainly carried out on true nepheline. The mean value he deduces for $(10\bar{1}0) : (20\bar{2}1) = 27°19'$ yields $a:c = 1 : 0{\cdot}8383483$. Using his measurements I have obtained for the mean value of $(0001) : (10\bar{1}1) = 44° 4'$, which yields $a:c = 1:0{\cdot}8383$.

The limits of variation for different crystals hc measured are 0·8364 and 0·8418, corresponding to angles $cp = 44° \frac{1}{4}'$ and $44° 11\frac{1}{4}'$ respectively. J. Strüver[11] gives for nepheline from the Alban Mts., $cp = 43° 50' 40''$, which yields $a : c = 1 : 0{\cdot}8318$ for one crystal, whilst measurements of the angles cp and cz yield an average value of $0{\cdot}8372 \pm 0{\cdot}0017$ for a second crystal. My measurements on the Monte Somma crystals yield a mean value of 0·8371 which varies for individual measurements on different crystals from 0·8324 to 0·8424. The available correlated data for axial ratio and chemical composition are contained in only three previously published papers. F. Stella Starrabba[42] has analysed nepheline crystals from Parco Chigi, Ariccia, Rome, Italy, and has measured the density, refractive index, and interfacial angles for many crystals. The weighted mean for the axial ratio derived from his measurements is 0·8370 and the individual measurements vary between 0·8339 and 0·8407, corresponding to angles $cp = 43° 55'$ and $44° 8'$. Correlated data for Monte Somma nephelines have not been hitherto available. Nepheline crystals in phonolite from Monte Ferru, Sardinia, have been measured and analysed by H. S. Washington and H. E. Merwin.[41] The weighted mean for a large number of measurements is $a : c = 1 : 0{\cdot}841$, and individual values fluctuate between 0·834 and 0·852. The remaining value for nepheline is given as $a : c = 1 : 0{\cdot}8368$ measured by F. Zambonini on ' pseudonepheline ' from Capo di Bove, Rome, Italy, and analysed by A. Serra.[32]

X-ray measurements have now made it possible to complete the axial ratio determinations on material unsuitable for crystallographic work (Table 3). The ratios deduced from the spacings have in the case of specimens nos. V, VI, and VII been confirmed by measurements on the Laue photographs. Plotting these axial ratios with the potassium content shows definitely that the axial ratio changes very little, but probably decreases with increase in potassium. This conclusion is confirmed by the correlated data of Washington, Stella Starrabba, and Zambonini (Table 7). Their plotted values fall very close to the line which best represents my experimental data. The probable conclusion to be drawn from this and the preceding result is that the increase of potassium increases the cell-volume, but increases the length of the base more than the height, so that the axial ratio itself decreases with increasing potassium.

Refractive index and dispersion measurements.

Chemical analyses of nepheline accompanied by optical data are scarce. The available data for refractive index are given in Table 7 and the dispersion data are given in Table 8. A serious attempt has therefore been made in the present work to obtain sufficient data in order to correlate the optical constants of nepheline with its chemical composition. Two well-known methods have been utilized in the measurement of refractive index and the birefringence of the nepheline specimens nos. I to IX. Many of the crystals are perfect hexagonal prisms and even fragments with prism-faces enclosing an angle of 60° can often be picked out when fully developed crystals are not available. Such specimens have been found to give perfect refracted images and the method of minimum deviation has therefore been used whenever possible. In the position of minimum deviation, of course, for a completely developed 60°-prism the direct reflection from a prism-face should coincide exactly with the refracted image. For a small crystal, however, the direct reflection is not sufficiently powerful to mask the refracted image, and if a nicol be used in front of the eyepiece of the telescope the reflected image almost disappears when the nicol is transmitting only the ordinary ray. The polarization produced at the reflecting face is sufficient to give this effect. It was observed that the reflected image viewed through an oriented nicol is dim over a large range of angles and is practically extinguished for the critical angle of incidence. This method gives the position of the extraordinary and ordinary refracted beams and a direct measurement can be made of the birefringence.

When a small crystal with its prism-faces all equally developed is carefully centred and rotated about its axis there are of course six positions corresponding to the six prism-angles in which the two refracted images may be observed. These images remain fixed as the crystal rotates, if the prism-angles are all equal to 60° and if the crystal is uniformly refracting. The usual formula for minimum deviation $n = \sin \frac{1}{2}(A+D)/\sin \frac{1}{2}A$ yields on differentiation assuming n constant $dD/dA = [\tan \frac{1}{2}(A+D)/\tan \frac{1}{2}A] - 1$. In the present case $A = 60°$ and D about 40°. Thus $dD/dA = (\tan 50°/\tan 30°) - 1 = 1{\cdot}064$. Hence, if the crystal is uniform, the variations of the minimum angle of deviation for the ordinary image as the crystal is rotated should be of the same order as the variation in prism-angle. For small crystals this variation of prism-angle is never greater than 5 minutes.

Any variations in the angle D much greater than 5′ could only be attributed to variations in refractive index of the crystal. Measurements have been made on two nepheline crystals, one in which the angles differ very little from the true angle 60° and the other where larger variations had been observed. The results indicate quite clearly that the variation of refractive index in the same crystal is very small. The readings are all capable of very accurate measurement and are independent of the setting of the telescope for the direct beam.

For the elaeolites and one or two nepheline crystals which could not be measured in this way prisms parallel to the optic axis were cut and polished with the grinding apparatus of H. H. Thomas and W. Campbell Smith. Small-angled prisms were used because the elaeolites and milky nephelines are almost opaque. The method of minimum deviation was also used for obtaining the refractive indices of nepheline for various wave-lengths. The values for four crystals are given in Table 8 and the dispersive powers have also been calculated from the smoothed n and λ curves.

In one or two rather large crystal fragments, not showing the requisite prism-faces for the previous method, the total reflection method was used. Beautiful facets were present on the crystals which would have been removed by grinding a suitable prism. Such crystals were therefore measured with the Abbé-Pulfrich refractometer and the readings obtained are consistent with the approximate immersion figures already given (p. 571).

The variation of refractive index of different crystals from the same matrix.

Apart from correlating the refractive indices of the specimens with the results of chemical analysis, which will be dealt with later, it was discovered that for all six nepheline specimens from Monte Somma, crystals from the same matrix gave very different refractive index measurements. Even an intergrowth of two small crystals from specimen no. VI gave $\omega_{Na} = 1{\cdot}5367$ for one crystal and $\omega_{Na} = 1{\cdot}5381$ for the second. Crystallographic measurements have been averaged for different crystals by previous observers, but refractive index measurements are usually carried out on one crystal. Zambonini,[36] however, has noted that two crystals of nepheline from the same sanidine block possessed different refractive indices namely $\omega = 1{\cdot}5376$ and $\omega = 1{\cdot}5359$ (Na-light); and he also gives refractive

Table 6. Densities and refractive indices of each nepheline crystal measured, together with Si *and* K *content in atoms per unit cell from Tables 2 and 3.*

(See figs. 2 and 4.)

Specimen.	Crystal.	ω.	ϵ.	$\omega-\epsilon$.	d.	Si.	K.
I	1	1·5341	—	—	2·614	8·29	0·76
	2	1·5304	1·5264	0·0040	2·617		
II	1	1·5387	—	—	2·621	8·39	0·97
	2	1·5368	1·5331	0·0037	2·610		
	3	1·5385	1·5349	0·0036	2·620		
	4	1·5369	—	—	2·625		
III	1	1·5355	1·5322	0·0033	2·616	8·44	1·18
	2	1·5378	1·5342	0·0036	2·602		
	3	1·5379	1·5347	0·0032	—		
	4	1·5384	1·5354	0·0030	2·631		
IV	1	1·5344	1·5312	0·0032	—	8·30	1·18
	2	1·5316	1·5284	0·0032	2·572		
	3	1·5312	1·5279	0·0033	—		
	4	1·5390	1·5362	0·0028	2·577		
	5	1·5299	1·5266	0·0033	2·576		
	6	1·5347	1·5313	0·0034	—		
V	1	1·5386	1·5354	0·0032	2·624	8·38	1·25
	2	1·5354	—	—	2·629		
VI	1	1·5373	1·5338	0·0035	2·608	8·16	1·29
	2	1·5390	1·5355	0·0035	2·602		
	3	1·5349	1·5316	0·0033	2·614		
	4	1·5383	1·5347	0·0036	2·620		
	5	1·5367	1·5334	0·0033	2·620		
	6	1·5383	1·5349	0·0034	2·626		
	7	1·5364	1·5330	0·0034	2·613		
	8	1·5381	1·5347	0·0034	—		
VII	1	1·5394	1·5360	0·0034	2·597	8·53	1·40
VIII	1	1·5403	1·5371	0·0032	2·591	9·27	1·83
	2	1·5392	1·5358	0·0034	2·567		
IX	1	1·5439	—	—	2·637	7·7	2·1
	2	1·5443	1·5404	0·0039	2·625		
	3	1·5461	1·5422	0·0039	2·647		
	4	1·547	1·543	0·004	2·655		

indices for two other crystals, one from a hiortdahlite-bearing syenite with $\omega_{Na} = 1{\cdot}5376$, and one from a pyroxene block $\omega_{Na} = 1{\cdot}5374$. All these specimens were from Monte Somma, and the last two were analysed by F. Stella Starrabba. Although the two refractive index measurements are practically identical, the chemical composition of the two is quite different. The second is poorer in silica and richer in potassium than the first. Zambonini states that he was unable to correlate refractive index and chemical composition, and from measurements made before and after heating to 810° C. and then

cooling he states that different heat treatment of different specimens may complicate the problem. He found that after heating, the refractive index rose from its initial value by about 0·002 (Na-light). However, different specimens did not behave in the same way and he drew no definite conclusions. Whilst allowing his conclusion on the different heat treatment of separate specimens, it is unlikely that differences of refractive index of crystals on the same matrix can be attributed to such a cause.

It is natural to assume that the variations in refractive index of crystals from the same matrix are an indication of differing chemical composition. F. Becke and J. E. Hibsch [48] have studied nepheline crystals from the phonolites of Bilin and Brüx, northern Bohemia, and found that they exhibit zonal growth. Their results, in the light of Bowen's [38] work on artificial calcium-rich nephelines, suggest that successive zones have different calcium contents thereby producing notable changes in birefringence. I have not found any signs of zonal growth in the nephelines I have studied and the variations in composition on the same matrix are presumably not restricted to calcium, but it is important to draw attention to the evidence that nepheline is extremely variable in composition as well as in refractive index.

The correlation of refractive index and the number of potassium atoms per unit cell.

In view of Zambonini's work and my own preliminary measurements I thought it advisable, in order to derive any relation between refractive index and chemical composition, to measure the refractive index for as many crystals as possible for each specimen chemically analysed (Table 6). In some cases it was impossible to detach more than two or three crystals suitable for exact measurement and it is not likely that the average value of refractive index for a few crystals would yield an accurate statistical mean. The value for each crystal has therefore been tabulated.

Fig. 4 shows graphically the marked difference in refractive index of crystals from the same matrix. It is also apparent that the refractive index increases with increase in potassium content. It can be seen that although the centre of each cluster defines the average composition and refractive index of the specimen, stragglers from one or two clusters approach each other and obviously correspond to a different composition. There are correlated data in existence for

Table 7. Correlated physical data of nepheline from the literature.

Lit. No.	Si atoms.	K atoms.	ω.	ϵ.	$\omega-\epsilon$.	d.	$a:c$.
32	7·99	2·57	1·5472	1·5435	0·0037	2·68	0·8368
36	8·24	1·33	1·5376	1·5339	0·0037	—	—
,,	8·41	1·04	1·5374	1·5341	0·0033	—	—
41	8·42	0·86	1·532–3	1·529	0·003–4	—	0·841
42	8·28	1·42	1·5417	1·5382	0·0035	2·65	0·837
45	8·10	1·55	1·540	1·538	0·002	2·664	—

Table 8. Refractive indices of nepheline for various wave-lengths.

Line.	Wave-length, λ.	No. VI, crystal 1. ω.	No. VI, crystal 1. ϵ.	No. VI, crystal 2. ω.	No. VI, crystal 2. ϵ.
— ...	7200 Å. ...	—	—	1·5341	1·5307
Li_α ...	6708 ...	1·5337	1·5307	1·5356	1·5321
H_α(C) ...	6563 ...	1·5343	1·5313	1·5361	1·5328
— ...	6250 ...	1·5354	1·5321	1·5372	1·5338
Na(D) ...	5893 ...	1·5373	1·5338	1·5384	1·5351
Hg yellow	5780 ...	1·5379	1·5346	1·5395	1·5360
Hg green	5461 ...	1·5389	1·5354	1·5406	1·5373
Tl_α ...	5350 ...	1·5398	1·5363	1·5413	1·5377
Hg blue ...	4916 ...	1·5426	1·5391	1·5443	1·5407
H_β(F) ...	4861 ...	1·5428	1·5394	1·5445	1·5410
Cs_β ...	4550 ...	1·5464	1·5428	1·5475	1·5440
Hg violet	4358 ...	—	—	1·5494	1·5462
H_γ(G′) ...	4340 ...	—	—	1·5500	1·5462

Line.	Wave-length, λ.	No. VII. ω.	No. VII. ϵ.	No. VIII, crystal 1. ω.	No. VIII, crystal 1. ϵ.
— ...	7200 Å. ...	1·5357	—	1·5371	—
Li_α ...	6708 ...	1·5363	1·5324	1·5377	1 5346
H_α(C) ...	6563 ...	1·5371	1·5339	1·5380	1·5350
— ...	6250 ...	1·5380	1·5349	1·5390	1·5363
Na(D) ...	5893 ...	1·5393	1·5359	1·5406	1·5374
Hg yellow	5780 ...	1·5404	1·5370	1·5417	1·5384
Hg green	5461 ...	1·5417	1·5381	1·5426	1·5394
Tl_α ...	5350 ...	1·5425	1·5384	1·5433	1·5402
Hg blue ...	4916 ...	1·5454	1·5419	1·5462	1·5429
H_β(F) ...	4861 ...	1·5453	—	1·5465	1·5431
Cs_β ...	4550 ...	—	—	—	—
Hg violet	4358 ...	1·5521*	1·5443*	1·5516	1·5486
H_γ(G′) ...	4340 ...	1·5526*	1·5443*	1·5518	1·5485

* Approximate values.

Dispersive power, $P=(n_F-n_C)/(n_{Na}-1)$.

Specimen.	Crystal.	P_ω.	P_ϵ.
VI	1	0·0164	0·0163
	2	0·0165	0·0163
VIII	1	0·0163	0·0156
VII	–	0·0160	0·0158
No. 42 (F. Stella Starrabba)		0·0162	0·0160

only six nepheline specimens (Table 7). These points lie satisfactorily near the line drawn through the new data. The increase in refractive index for one potassium atom has been measured from fig. 4 as 0·006 to 0·008. The birefringence also appears to increase in the same direction, but the increase is too small to deduce any

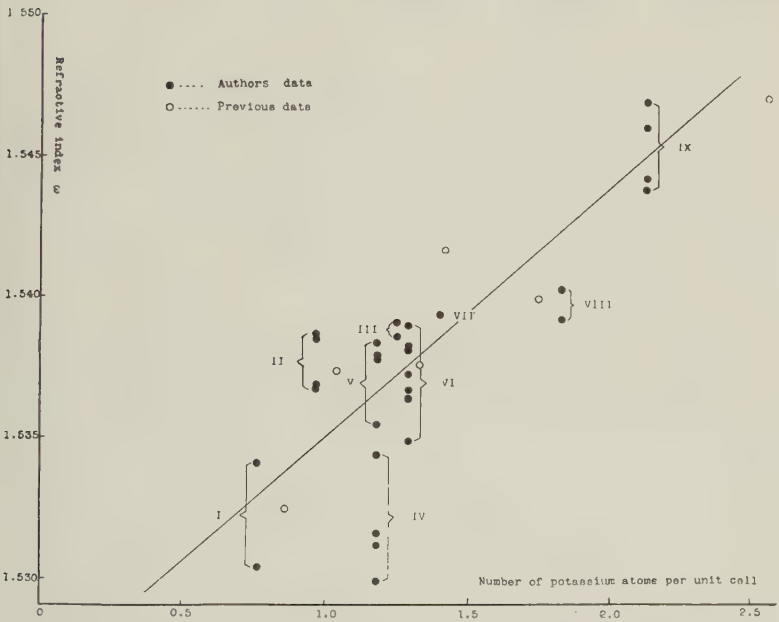

FIG. 4. Graph plotting the number of potassium atoms per unit cell against the refractive index (ω) of each crystal of nepheline measured.

certain relations. It is noteworthy that the refractive index of 'pseudonepheline' is the highest recorded for nepheline and no analysis records a higher potassium content. Penfield [17a] has recorded a refractive index of $\omega = 1{\cdot}5469$ for elaeolite from Arkansas, and from the data we have obtained this should have a potassium content of 2·55 atoms per unit cell. No analysis exists, however, to confirm this conclusion. The low refractive indices of the two nepheline specimens nos. I and IV are probably to be attributed to low potassium content. It will be noted also that one of these specimens, no. IV, yielded a low oxygen figure (Table 3). Its low density accounts in part for the low figure of 31·1, but the latter is influenced to a much greater extent by the percentage of oxygen

given by chemical analysis. In other words the cell-volume measured by X-ray methods and the refractive index do not correspond to the material analysed. Such a conclusion must apply to each specimen here studied to a greater or less degree; if the number of oxygen atoms per unit cell is near 32, then the cell-volume, and presumably the refractive index, are associated with the given chemical composition.

The space-group and the structure-scaffolding of nepheline.

The section dealing with nepheline will be concluded with an account of the work which has been done on the space-group and the structure. Pl. XXI, fig. 7, shows a Laue photograph of a nepheline crystal (specimen no. VI, crystal 2) taken along the *c*-axis. The crystal is so oriented that an *a*-axis is horizontal. A gnomonic projection of this photograph has been made and the indices are given in Table 9. It is obvious that the Laue photograph possesses only a hexagonal axis and no planes of symmetry. Care has been taken in giving the relative intensities of the spots which reveal the lack of symmetry-planes, for since a pair of such spots corresponds to the same wave-length their relative intensities are a measure of the structure intensities for the two planes. All the spots observed correspond to wave-lengths ranging from 0·322 to about 4·0 Å. The short wave limit calculated from the voltage applied to the X-ray tube is 0·30 Å. In attempting to deduce any structure factors from the Laue photograph caution is necessary in particular for spots $(70\bar{7}3)$, $(44\bar{8}3)$, $(32\bar{5}1)$ and $(10.0.\bar{1}\bar{0}.3)$, $(72\bar{9}2)$, since their corresponding wave-lengths lie close to the absorption limits for bromine ($\lambda = 0{\cdot}918$ Å.) and silver ($\lambda = 0{\cdot}485$ Å.) respectively. In Table 10 I have also given the indices of the spots of a rotation photograph about the *c*-axis reproduced in Pl. XXII, fig. 9. The photograph was taken using a molybdenum anticathode and a zirconium filter.

A direct physical solution of the nepheline structure has not yet been offered, but the space-group of nepheline appears to be satisfactorily established. Gottfried,[52] Schiebold,[56] and Jaeger[50] have all found the space-group to be C_6^6, and this conclusion is in agreement not only with X-ray data but also with Baumhauer's[21] experiments on the etch-figures of nepheline. I have made oscillation photographs of nepheline crystals used for spacing measurements to obtain the odd orders of the base reflections (0001), (0003), &c., without success. Dr. W. A. Wooster has also detected the pyro-electric

effect of nepheline crystals from nos. III, VI, and VIII immersed in liquid air. He states that a definite effect was observed, but owing to the small size of the crystals he failed to obtain the direction of the pyro-electric axis. There seems little doubt, therefore, that the space-group has been correctly chosen.

It has already been stated that the recalculation of nepheline analyses giving the number of atoms per unit cell all resulted in a constant sum of $Si + Al = 16$, and this may be interpreted as a result of the substitution of Si for Al in nepheline without alteration of structure and as we have seen without appreciable alteration in cell-size. If the substitution is carried to its logical conclusion then it appears that a form of silica would result. Gibbs [47] has studied the structures of the various forms of silica and his data for β-tridymite are $a = 5{\cdot}03$, $c = 8{\cdot}22$ Å., for the cell-edges of the unit hexagonal cell. The rhomb-based cell contains $4SiO_2$ and the structure consists of linked tetrahedra of Si surrounded by four oxygen atoms. If half the silicon atoms be replaced by aluminium the structure becomes polar (fig. 5). The disappearance of the vertical planes of symmetry might be explained in terms of a rotation of each tetrahedron of Si and O atoms and Al and O atoms about the trigonal axis, but this would not account for the a dimension now being doubled. A plan of the structure perpendicular to an a-axis (fig. 5 b) also shows obvious gaps for the alkali atoms, but symmetry conditions are not sufficient to fix either the exact position of the oxygen or the alkali atoms. The Si and Al atoms are fixed by symmetry on the trigonal axes and the alkali atoms are probably situated on and around hexad axes. The gaps shown in fig. 5 which probably accommodate the alkali atoms are about the diameter of an oxygen atom, i.e. 2·5 to 2·7 Å. The diameters of the sodium and potassium atoms are 2·0 and 2·6 Å. respectively. The disturbance caused by the entrance of large anions into the simple structure postulated in fig. 5 might very easily cause some distortion. The actual details of such distortion can only be studied by direct physical methods.

Prof. W. L. Bragg has been good enough to inform me that he has arrived at a similar structure by assuming Gottfried's determination of the space-group and the sizes of the atoms, whilst Schiebold [56] has recently published X-ray data on nepheline from Pargo Chigi, Ariccia, Italy. He has confirmed Gottfried's space-group determination and has suggested that the structure is derived from tridymite,

thereby explaining the excess silica usually found in nepheline analyses. Although no detailed structure has been worked out, the scaffolding seems to be firmly established and it is interesting to

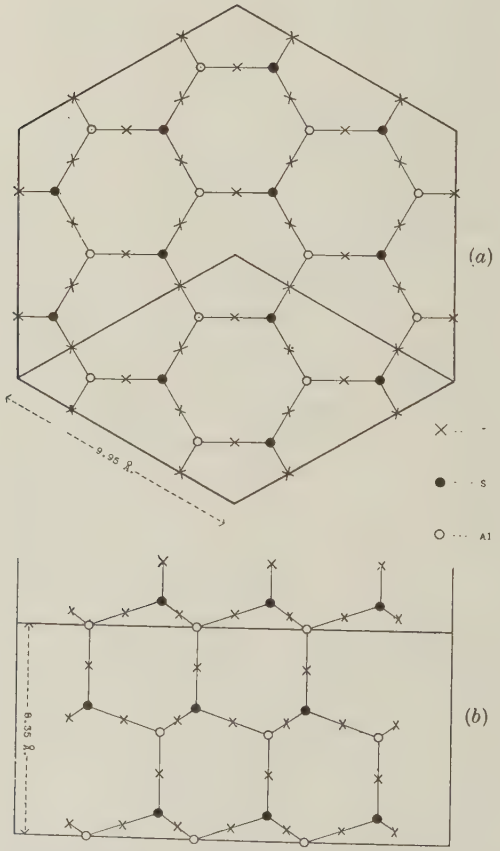

Fig. 5. Two views of the scaffolding of the nepheline structure: (*a*) perpendicular to the *c*-axis; (*b*) perpendicular to an *a*-axis.

note that the controversies on the interpretation of nepheline analyses change their aspect. Bowen's [37, 43] thermal work led him to conclude that natural nephelines are to be regarded as solid solutions of nepheline, kaliophilite, and plagioclase, whereas Morozewicz's [54] careful chemical analyses of elaeolite from the mariupolite rocks of Mariu-

pol, Russia, led him to write the formula $K_2Al_2Si_3O_{10}.4Na_2Al_2Si_2O_8$. Morozewicz looked upon nepheline as a double salt rather than an isomorphous replacement of potassium and sodium. Other views have been held too numerous to discuss here; references are to be found in the list of literature appended.

The work described in this paper enables us to write the contents of the unit cell of nepheline as $Si_{16-n}Al_n(Na,K,\frac{1}{2}Ca)_nO_{32}$ with the possible inclusion of Mg with the alkalis (p. 580). The variations in composition of nepheline may now be regarded as the replacement of Al by Si and Na by K and Ca in such a way that the nepheline structure is not altered and so that the valency conditions are fulfilled. It has been shown that the increase of potassium content increases the cell size. This may perhaps be referred to the size of the potassium atom being larger than that of sodium.

I have found that the 'pseudonepheline' crystals from Capo di Bove (specimen no. IX) with high potassium content yield Laue photographs typical for nepheline and have the same value for the axial ratio, namely 0·84. These photographs, however, do not show the lack of vertical symmetry-planes so clearly. Many spots of unequal intensity on the other nepheline Lauegrams are for the 'pseudonepheline' photographs of approximately equal intensity. There is a possibility that the problem thus presented is complicated by twinning. Baumhauer[21] has figured nepheline crystals twinned so that opposite ends of the *c*-axis of the separate individuals lie together. Such twinning from the suggested structure of fig. 5 seems highly probable and of course would account for the increase in symmetry of the Laue photograph. These crystals of 'pseudonepheline' are so small that it has not been possible to etch the faces and decide the matter.

Table 9. *Indices and intensities of spots on a Laue photograph of nepheline (no. VI, crystal* 2*) taken perpendicular to the c-axis.* (Pl. XXI, fig. 7.)

Index.	Intensity.	Index.	Intensity.	Index.	Intensity.	Index.	Intensity.
(20$\bar{2}$1)	*m*	(8.3.$\bar{1}$1.5)	*s*	(61$\bar{7}$3)	*vvw*	(1.11.$\bar{1}$2.5)	*vvw*
(71$\bar{8}$4)	*m*	(3.8.$\bar{1}$1.5)	*m*	(16$\bar{7}$3)	*w*	(10.2.$\bar{1}$2.5)	*m*
(17$\bar{8}$4)	*vvw*	(90$\bar{9}$4)	*w*	(52$\bar{7}$3)	*vw*	(2.10.$\bar{1}$2.5)	*w*
(11.0.$\bar{1}$1.5)	*vw*	(72$\bar{9}$4)	*m*	(25$\bar{7}$3)	*vvw*	(8.4.$\bar{1}$2.5)	*vvw*
(10.1.$\bar{1}$1.5)	*ms*	(27$\bar{9}$4)	*vw*	(43$\bar{7}$3)	*m*	(4.8.$\bar{1}$2.5)	*ms*
(1.10.$\bar{1}$1.5)	*m*	(54$\bar{9}$4)	*w*	(34$\bar{7}$3)	*w*	(7.5.$\bar{1}$2.5)	*ms*
(9.2.$\bar{1}$1.5)	*m*	(45$\bar{9}$4)	*vw*	(7.7.$\bar{1}$4.6)	*ms*	(5.7.$\bar{1}$2.5)	*ms*
(2.9.$\bar{1}$1.5)	*ms*	(70$\bar{7}$3)	*vs*	(11.1.$\bar{1}$2.5)	nil	(6.6.$\bar{1}$2.5)	*vw*

Table 9—continued.

Index.	Intensity.	Index.	Intensity.	Index.	Intensity.	Index.	Intensity.
(50$\bar{5}$2)	*ms*	(72$\bar{9}$3)	*vs*	(2.9.$\bar{11}$.3)	*s*	(14$\bar{5}$1)	*vs*
(41$\bar{5}$2)	*w*	(27$\bar{9}$3)	*vs*	(8.3.$\bar{11}$.3)	*s*	(7.3.$\bar{10}$.2)	*ms*
(14$\bar{5}$2)	*vw*	(21$\bar{3}$1)	*s*	(3.8.$\bar{11}$.3)	*vw*	(3.7.$\bar{10}$.2)	nil
*(32$\bar{5}$2)	*w*	(12$\bar{3}$1)	*s*	(40$\bar{4}$1)	*m*	(32$\bar{5}$1)	*vs*
*(23$\bar{5}$2)	nil	(9.6.$\bar{15}$.5)	*vw*	(71$\bar{8}$2)	*ms*	(23$\bar{5}$1)	*vvs*
(7.3.$\bar{10}$.4)	*vvw*	(6.9.$\bar{15}$.5)	*vw*	(17$\bar{8}$2)	*m*	(5.5.$\bar{10}$.2)	*s*
(3.7.$\bar{10}$.4)	*w*	(54$\bar{9}$3)	*s*	(10.2.$\bar{12}$.3)	*m*	(11.0.$\bar{11}$.2)	*vvw*
(12.1.$\bar{13}$.5)	*vw*	(45$\bar{9}$3)	*s*	(2.10.$\bar{12}$.3)	*ms*	(9.2.$\bar{11}$.2)	*ms*
(1.12.$\bar{13}$.5)	nil	(33$\bar{6}$2)	*ms*	*(31$\bar{4}$1)	*vs*	(2.9.$\bar{11}$.2)	*vvw*
(10.3.$\bar{13}$.5)	*w*	(9.7.$\bar{16}$.5)	*w*	*(13$\bar{4}$1)	*vs*	(8.3.$\bar{11}$.2)	*ms*
(3.10.$\bar{13}$.5)	*m*	(7.9.$\bar{16}$.5)	*w*	(8.4.$\bar{12}$.3)	*vw*	(3.8.$\bar{11}$.2)	*m*
(8.5.$\bar{13}$.5)	*w*	(8.8.$\bar{16}$.5)	*w*	(4.8.$\bar{12}$.3)	*vw*	(7.4.$\bar{11}$.2)	*vw*
(5.8.$\bar{13}$.5)	*w*	(11.2.$\bar{13}$.4)	nil	(53$\bar{8}$2)	*vs*	(4.7.$\bar{11}$.2)	*vw*
(80$\bar{8}$3)	*m*	(2.11.$\bar{13}$.4)	*w*	(35$\bar{8}$2)	*vs*	(6.5.$\bar{11}$.2)	*vw*
(71$\bar{8}$3)	*w*	(9.4.$\bar{13}$.4)	nil	(7.5.$\bar{12}$.3)	*s*	(5.6.$\bar{11}$.2)	*m*
(17$\bar{8}$3)	*ms*	(4.9.$\bar{13}$.4)	*w*	(5.7.$\bar{12}$.3)	*s*	(60$\bar{6}$1)	*s*
(62$\bar{8}$3)	*m*	(8.5.$\bar{13}$.4)	*w*	(22$\bar{4}$1)	*vs*	(51$\bar{6}$1)	*vs*
(26$\bar{8}$3)	*w*	(5.8.$\bar{13}$.4)	nil	(11.2.$\bar{13}$.3)	*vvw*	(15$\bar{6}$1)	*vs*
(53$\bar{8}$3)	*w*	(10.0.$\bar{10}$.3)	*m*	(2.11.$\bar{13}$.3)	*vw*	(42$\bar{6}$1)	*s*
(35$\bar{8}$3)	*vvw*	(9.1.$\bar{10}$.3)	*s*	(10.3.$\bar{13}$.3)	nil	(24$\bar{6}$1)	*vs*
(44$\bar{8}$3)	*vs*	(1.9.$\bar{10}$.3)	*vvw*	(3.10.$\bar{13}$.3)	*vw*	(7.5.$\bar{12}$.2)	*w*
(11.0.$\bar{11}$.4)	*vw*	(8.2.$\bar{10}$.3)	*s*	(9.4.$\bar{13}$.3)	*w*	(5.7.$\bar{12}$.2)	*w*
(9.2.$\bar{11}$.4)	*vvw*	(2.8.$\bar{10}$.3)	*s*	(4.9.$\bar{13}$.3)	*vw*	(33$\bar{6}$1)	*s*
(2.9.$\bar{11}$.4)	*ms*	(7.3.$\bar{10}$.3)	*ms*	(8.5.$\bar{13}$.3)	*m*	(70$\bar{7}$1)	*s*
(8.3.$\bar{11}$.4)	*vvw*	(3.7.$\bar{10}$.3)	*ms*	(5.8.$\bar{13}$.3)	*m*	(61$\bar{7}$1)	*vw*
(3.8.$\bar{11}$.4)	*vw*	(6.4.$\bar{10}$.3)	*ms*	(90$\bar{9}$2)	*m*	(16$\bar{7}$1)	*m*
(7.4.$\bar{11}$.4)	*m*	(4.6.$\bar{10}$.3)	*vvw*	(81$\bar{9}$2)	*ms*	(52$\bar{7}$1)	*m*
(4.7.$\bar{11}$.4)	*w*	(5.5.$\bar{10}$.3)	*s*	(18$\bar{9}$2)	*s*	(25$\bar{7}$1)	*vvw*
(14.0.$\bar{14}$.5)	*w*	(70$\bar{7}$2)	*vvs*	(72$\bar{9}$2)	*s*	(43$\bar{7}$1)	*s*
(12.2.$\bar{14}$.5)	*w*	(61$\bar{7}$2)	*ms*	(27$\bar{9}$2)	*vs*	(34$\bar{7}$1)	*s*
(2.12.$\bar{14}$.5)	*w*	(16$\bar{7}$2)	*s*	(63$\bar{9}$2)	*m*	(71$\bar{8}$1)	*w*
(11.3.$\bar{14}$.5)	*vw*	(52$\bar{7}$2)	*s*	(36$\bar{9}$2)	*vvw*	(17$\bar{8}$1)	nil
(3.11.$\bar{14}$.5)	*m*	(25$\bar{7}$2)	*vs*	(54$\bar{9}$2)	*w*	(62$\bar{8}$1)	*w*
(9.5.$\bar{14}$.5)	*w*	(43$\bar{7}$2)	*s*	(45$\bar{9}$2)	*vs*	(26$\bar{8}$1)	*w*
(5.9.$\bar{14}$.5)	*m*	(34$\bar{7}$2)	*s*	(9.5.$\bar{14}$.3)	*vw*	(53$\bar{8}$1)	*m*
(30$\bar{3}$1)	*w*	(7.7.$\bar{14}$.4)	*vw*	(5.9.$\bar{14}$.3)	*w*	(35$\bar{8}$1)	*s*
(81$\bar{9}$3)	*m*	(11.0.$\bar{11}$.3)	*vvw*	(50$\bar{5}$1)	*vvs*	(44$\bar{8}$1)	*w*
(18$\bar{9}$3)	*m*	(10.1.$\bar{11}$.3)	*vs*	(9.1.$\bar{10}$.2)	*m*		
(51$\bar{6}$2)	*ms*	(1.10.$\bar{11}$.3)	*s*	(1.9.$\bar{10}$.2)	*m*		
(15$\bar{6}$2)	*ms*	(2.9.$\bar{11}$.3)	*w*	(41$\bar{5}$1)	*s*		

* Superposed upon the true Laue spots (32$\bar{5}$2) and (31$\bar{4}$1) are streaks due to diffracted characteristic radiation from copper and tungsten. (32$\bar{5}$2) and (23$\bar{5}$2) diffract Cu–K_α (λ = 1·539 Å.); (31$\bar{4}$1) and (13$\bar{4}$1) diffract W–$L_{\beta 1}$ (λ = 1·279 Å.). Distance of crystal to plate, 3·5 cm. *s* = strong, *m* = medium, *w* = weak, *vs* = very strong, &c.

Table 10. *Indices and intensities of spots on a rotation photograph of nepheline (no. VI, crystal* 2*) about the* c*-axis.* (Pl. XXII, fig. 9.)

Equator.	1st layer-line.	2nd layer-line.	3rd layer-line.	4th layer-line.	5th layer-line.	6th layer-line.
—	—	$(10\bar{1}2)$ *w*	$(10\bar{1}3)$ *vw*	$(10\bar{1}4)$ *m*	—	$(10\bar{1}6)$ *ms*
$(2\bar{1}\bar{1}0)$ *w*	$(2\bar{1}\bar{1}1)$ *vvw*	—	—	—	$(2\bar{1}\bar{1}5)$ *w*	—
$(20\bar{2}0)$ *m*	$(20\bar{2}1)$ *s*	$(20\bar{2}2)$ *vs*	$(20\bar{2}3)$ *s*	$(20\bar{2}4)$ *m*	$(20\bar{2}5)$ *vs*	—
$(3\bar{1}20)$ *vs*	$(3\bar{1}21)$ *w*	$(3\bar{1}\bar{2}2)$ *ms*	$(3\bar{1}\bar{2}3)$ *m*	$(3\bar{1}\bar{2}4)$ *w*	$(3\bar{1}\bar{2}5)$ *vw*	$(3\bar{1}\bar{2}6)$ *vw*
$(30\bar{3}0)$ *vs*	—	$(30\bar{3}2)$ *vw*	—	$(30\bar{3}4)$ *w*	—	$(30\bar{3}6)$ *s*
$(22\bar{4}0)$ *ms*	$(22\bar{4}1)$ *vw*	—	—	—	—	$(22\bar{4}6)$ *m*
$(4\bar{1}30)$ *s*	$(4\bar{1}31)$ *s*	$(4\bar{1}32)$ *m*	$(4\bar{1}33)$ *vw*	$(4\bar{1}34)$ *w*	$(4\bar{1}35)$ *ms*	$(4\bar{1}36)$ *m*
$(40\bar{4}0)$ *m*	—	$(40\bar{4}2)$ *w*	$(40\bar{4}3)$ *w*	$(40\bar{4}4)$ *vw*	$(40\bar{4}5)$ *w*	$(40\bar{4}6)$ *vw*
$(5\bar{2}30)$ *m*	$(5\bar{2}\bar{3}1)$ *m*	$(5\bar{2}\bar{3}2)$ *vw*	$(5\bar{2}\bar{3}3)$ *ms*	—	—	—
$(5\bar{1}40)$ *m*	$(5\bar{1}41)$ *w*	$(5\bar{1}\bar{4}2)$ *vw*	$(5\bar{1}\bar{4}3)$ *ms*	—	—	—
$(50\bar{5}0)$ *vw*	$(50\bar{5}1)$ *w*	$(50\bar{5}2)$ *w*	$(50\bar{5}3)$ *m*	—	$(50\bar{5}5)$ *ms*	—
$(6\bar{2}40)$ *ms*	$(6\bar{2}41)$ *vw*	$(6\bar{2}\bar{4}2)$ *w*	$(6\bar{2}\bar{4}3)$ *m*	—	$(6\bar{2}\bar{4}5)$ *w*	$(6\bar{2}\bar{4}6)$ *vw*
$(6\bar{1}50)$ *ms*	$(6\bar{1}\bar{5}1)$ *vw*	$(6\bar{1}\bar{5}2)$ *vw*	—	—	$(6\bar{1}\bar{5}5)$ *w*	—
$(60\bar{6}0)$ *vw*	$(60\bar{6}1)$ *vvw*	$(60\bar{6}2)$ *vw*	$(60\bar{6}3)$ *m*	$(60\bar{6}4)$ *w*	$(60\bar{6}5)$ *w*	$(60\bar{6}6)$ *m*
$(7\bar{2}50)$ *vs*	—	$(7\bar{2}\bar{5}2)$ *m*	—	$(7\bar{2}\bar{5}4)$ *vw*	—	—
$(7\bar{1}60)$ *w*	—	$(7\bar{1}\bar{6}2)$ *vw*	—	—	—	—
$(70\bar{7}0)$ *m*	$(70\bar{7}1)$ *vw*	$(70\bar{7}2)$ *ms*	$(70\bar{7}3)$ *m*	—	$(70\bar{7}5)$ *m*	—
$(8\bar{2}60)$ *w*	—	$(8\bar{2}\bar{6}2)$ *vw*	—	—	—	—

The distance of plate to crystal = 3·9 cm.
Molydenum radiation $\lambda = 0{\cdot}71$ Å. was used filtered by zirconium.

Kaliophilite.

Owing to the lack of material it has not been possible to study a series of specimens of this mineral and thus correlate the physical properties with chemical composition. The attempt has been made rather to find the relation between nepheline and kaliophilite and to carry out X-ray and other physical measurements on material definitely shown by chemical analysis to be kaliophilite. Two good specimens of kaliophilite were available, one from the British Museum collection (B.M. 68763) and a very fine one, no. 673, kindly lent for study by Dr. K. W. Earle from the Johnston-Lavis collection at University College, London. These specimens are numbered X and XI respectively in Table 11. The original labels with these specimens bear the name 'Facellite' (E. Scacchi, 1888),[20] but, as will be shown below, the chemical and optical properties and the densities of fresh material from both specimens are those for kaliophilite (B. Mierisch, 1886).[19] In Hintze's 'Handbuch der Mineralogie', 1897, the two names are considered to represent distinct minerals, presumably on the density determination (2·4926) of E. Scacchi.[20]

The specimens examined consist of glassy acicular bundles of the mineral in cavities of a dark augite and brown biotite block. Material suitable for physical and chemical work was picked by hand, and, to avoid loss by bromoform separations, each fragment set aside for chemical analysis was carefully examined with a lens to make quite sure it was free from inclusions or adherent impurities. In the case of specimen no. X only 0·02 gram was available, but the analysis is sufficiently accurate to show that the mineral analysed is kaliophilite (Table 11). The densities were determined by the method already described. The refractive indices were first determined by the Becke line method, but in the case of specimen no. XI it was possible to grind a small-angle prism and determine the refractive index by the method of minimum deviation for five different wave-lengths. The dispersive power calculated from the smoothed n and λ curve is 0·016 (Table 12). The fragments of nos. X and XI used for density and refractive index work were then studied by X-ray methods.

Gossner[58] has already published X-ray data for kaliophilite, and he offers two alternatives for the cell size: $a = 27{\cdot}01$, $c = 8{\cdot}59$ Å., $c/a = 0{\cdot}318$; and $a = 15{\cdot}59$, $c = 8{\cdot}59$ Å., $c/a = 0{\cdot}55$. The second set of values he obtained by neglecting certain weak layer-lines on his rotation photographs and presumes that they are more likely to be correct since they are of the same order as those obtained for other silicates. In any case his preliminary measurements indicate a marked difference between the X-ray rotation photographs of nepheline and kaliophilite.

Laue and rotation photographs of the kaliophilite specimen no. X had been obtained before Gossner's work was published. Pl. XXI, fig. 8, shows the reproduction of the Laue photograph of kaliophilite, and it will be noted that it has planes of symmetry as well as hexagonal symmetry. It is also obvious from the closer array of spots in the kaliophilite picture that the unit cell is larger than that of nepheline. The rotation photograph about the c-axis reproduced in Pl. XXII, fig. 10, shows that the cell-height (Table 11) is about the same as that of nepheline. Whereas the layer-lines of both rotation photographs in Pl. XXII are similarly spaced, the row-lines are much closer together than in the nepheline photograph, indicating that the base of the hexagonal cell is larger, $a = 27{\cdot}0$ Å. This result has been checked by rotation and oscillation photographs about the a-axis and about an axis at 30° to a. Oscillation photo-

Table 11. *New chemical and physical data for kaliophilite.*

Chemical analyses.

	SiO_2.	Al_2O_3.	CaO.	Na_2O.	K_2O.	Total.	% oxygen.
X ...	38·0	28·8	0·5	trace	32·2	99·5	39·4
XI ...	39·2	33·36	0·47	2·88	24·13	100·04	42·77

The amount of material used for no. X, 0·0208 gram.

Molecular ratios.

	SiO_2.	Al_2O_3.	CaO.	Na_2O.	K_2O.
X ...	0·632	0·565	0·009	—	0·684
XI ...	0·6525	0·6545	0·0084	0·0929	0·5123

Number of atoms per unit cell.

	Si.	Al.	Ca.	Na.	K.	Si+Al.	ΣR.
X	55	50	1	—	60	105	62
XI	54·3	54·4	0·7	7·7	42·6	108·7	51·7

Physical data.

	Density, d.	Refractive Index, ω.	ϵ.	$\omega-\epsilon$.	Length of cell-edge a.	Length of cell-height c.	$\frac{c}{a}$
X	2·598	1·531	1·527	0·004	26·7 Å.	8·49 Å.	0·318
XI	2·606	1·5296	1·5258	0·0038	27·0	8·51	0·315

Table 12. *Refractive indices of kaliophilite (no. XI) for different wave-lengths.*

Line.	Wave-length.	ω.
— ...	6250 Å. ...	1·527
Na(D) ...	5893 ...	1·530
Hg green ...	5461 ...	1·532
Tl_α... ...	5350 ...	1·533
H_β(F) ...	4861 ...	1·536

Dispersive power, $P=(n_F-n_C)/(n_{Na}-1)$, obtained from the smoothed ω and λ curve, 0·016.

graphs to obtain the a and c spacings for nos. X and XI have been taken for the planes (0006) and (12.0.$\overline{1}\overline{2}$.0).

A gnomonic projection of the Laue photograph has yielded the indices given in Table 14. This photograph was taken under the same conditions as the Laue photograph of nepheline and the wave-lengths range from 0·30 to about 4·0 Å., the short wave limit also agreeing with that calculated from the applied voltage. The same caution should be observed in utilizing the observed intensities of spots produced by different wave-lengths; it has not been possible in this case to indicate those spots corresponding to wave-lengths lying close to the absorption limits for bromine and silver, since the spots are so much closer together. The rotation photograph of kaliophilite is difficult to index completely owing to the large a

dimension. The second and fourth layer-lines are weak, and the strong spots indexed with certainty are $(33\bar{6}0)$ *m*, $(33\bar{6}2)$ *vs*, $(90\bar{9}0)$ *vs*, $(5.5.\bar{10}.6)$ *s*, and $(6.6.\bar{12}.0)$ *s*.

From the unit cell and density measurements it has been possible to calculate the molecular weight of the unit-cell contents, and this approximates closely to $54KAlSiO_4$. The chemical analyses are not in this case sufficiently accurate to yield a direct determination of the number of oxygen atoms in the unit cell, but assuming from the above result 216 per unit cell, all previous analyses (Table 13) and Mr. Hey's (Table 11) give a reasonably constant figure for the Si + Al content. The sodium content of kaliophilite from this and previous work is less than the potassium content of nepheline.

Table 13. *Number of atoms per unit cell of kaliophilite, calculated from previous analyses.*

Lit. No.	Si.	Al.	Ca.	Na.	K.	Si+Al.	ΣR.	*d*.
19	52·7	53·8	3·3	6·2	48·8	106·5	61·6	2·602
20	53·3	55·1	—	1·0	52·8	108·4	53·8	2·493
36	54·4	53·6	trace	5·8	47·9	108·0	53·7	2·628
49	54·9	53·0	0·5	10·6	41·0	107·9	53·2*	2·61

* In the sum of the alkali atoms is included 0·3 atoms of magnesium.

For no. 49 (Mügge) ... ... $\omega = 1{\cdot}5316$, $\epsilon = 1{\cdot}5273$ (yellow).

The X-ray data yield axial ratios $c/a = 0{\cdot}318$ and $c/a = 0{\cdot}315$ for nos. X and XI respectively. Careful examination of the material at my disposal failed to reveal any pyramidal planes suitable for direct measurement of the axial ratio. Even the prism-faces show many neighbouring vicinal forms and I failed to observe a (0001) cleavage. F. Zambonini,[36] however, has succeeded in obtaining a reflection from a pyramidal plane of an isolated prism of kaliophilite. He gives $a : c = 1 : 0{\cdot}8382$, and I have calculated from his measurements the limits of error of this determination to be $\pm 0{\cdot}001$. My X-ray data do not agree with this figure, nor is there any simple ratio between the two.

Comparing the *a* dimensions of kaliophilite and nepheline it is clear that 27/10 = approximately $3(\sqrt{3}/2)$. In fact we may look upon the kaliophilite cell as built up from three nepheline cells in juxtaposition, the true *a* dimension not being trebled but fixed in a direction of 30° to the original nepheline cell-side. Fig. 6 shows this arrangement, and we must postulate that the presence of the large potassium atoms in the gaps in this structure has produced sufficient distortion to yield the large cell measured by X-ray

methods. The distortion will probably prove to be of the same type as the distortion of the nepheline structure. The larger cell and the planes of symmetry of kaliophilite may then possibly be explained on the simple lines before suggested, namely a threefold 'twinning' or 'parallel growth' of the nepheline cell. In my work on nepheline it is shown that the cell-size increases with increase in potassium

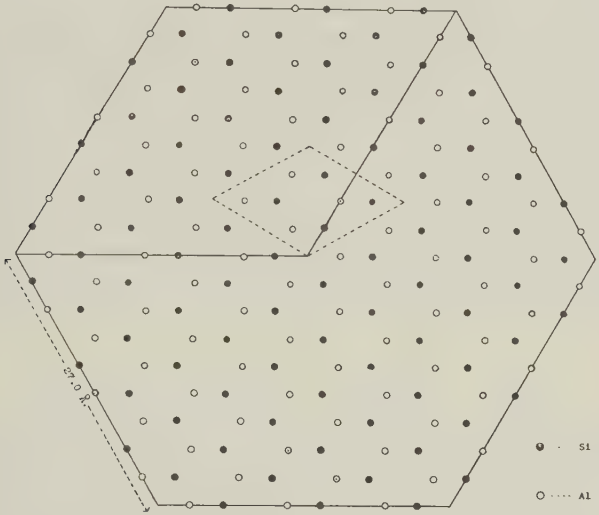

FIG. 6. Plan of a possible kaliophilite scaffolding built up from nepheline cells. The dotted outline is a nepheline unit cell.

content. The kaliophilite structure may be regarded as built up from nepheline cells having the cell-sides $a = (27/3) \times (2/\sqrt{3}) = 10{\cdot}4$ Å., and $c = 8{\cdot}5$ Å. The almost complete replacement of sodium by potassium has stretched the cell to these dimensions and the consequent distortion of the tetrahedral framework has resulted in the increase of the repetition distance of the more intricate atomic pattern from 10·4 to 27 Å. It will be noted, however, that the c spacing is still of the same order though larger. For nepheline the axial ratio appears to decrease with increase of potassium and the kaliophilite results give the same conclusion, namely that the replacement of sodium by potassium increases the a spacing more than the c spacing and therefore reduces the axial ratio (p. 587).

In the interests of future workers, especially those using X-ray methods, I would draw attention to two unique specimens of kaliophilite in the Göttingen collection described by O. Mügge,[49] which consist of milky-white crystals on ejected blocks from Monte Somma, Vesuvius. The crystals reach a size of 5 mm. across and 17 mm. long and their chemical analysis and optical properties prove them to be kaliophilite. On the basis of Mügge's work the white crystals of nepheline low in refractive index found on specimens nos. I and IV were at first thought to be kaliophilite, but chemical analyses and Laue photographs have definitely shown them to be nepheline. Their low refractive index values have already been discussed. In view of the much smaller crystals of kaliophilite usually met with it would be desirable to possess further data on the Göttingen specimens. Such good crystals would be eminently suitable for work on X-ray structure. It is significant that the analyses of these crystals reveal a higher sodium content than is usual for kaliophilite, and that zoning of the crystals accompanied by variations in birefringence has also been observed.

Table 14. *Indices and intensities of spots on a Laue photograph of kaliophilite (no. X) taken perpendicular to the c-axis.* (Pl. XXI, fig. 8.)

Index.	Intensity.	Index.	Intensity.	Index.	Intensity	Index.	Intensity.
(50$\bar{5}$1)	*vvw*	(61$\bar{7}$1)	*w*	(18.5.2$\bar{3}$.3)	*w*	(10.7.1$\bar{7}$.2)	*w*
(15.1.1$\bar{6}$.3)	*vvw*	(17.4.2$\bar{1}$.3)	*vvw*	(17.6.2$\bar{3}$.3)	*vw*	(22.3.2$\bar{5}$.3)	*m*
(15.2.1$\bar{7}$.3)	*vvw*	(16.5.2$\bar{1}$.3)	*m*	(15.8.2$\bar{3}$.3)	*vw*	(21.4.2$\bar{5}$.3)	*w*
(60$\bar{6}$1)	*w*	(52$\bar{7}$1)	*vw*	(14.9.2$\bar{3}$.3)	*w*	(19.6.2$\bar{5}$.3)	*vw*
(17.1.1$\bar{8}$.3)	*vw*	(14.7.2$\bar{1}$.3)	*vvw*	(12.11.2$\bar{3}$.3)	*vw*	(18.7.2$\bar{5}$.3)	*w*
(16·2.1$\bar{8}$.3)	*vw*	(13.8.2$\bar{1}$.3)	*vw*	(80$\bar{8}$1)	*vw*	(16.9.2$\bar{5}$.3)	*w*
(51$\bar{6}$1)	*vw*	(43$\bar{7}$1)	*vw*	(23.1.2$\bar{4}$.3)	*vw*	(13.12.2$\bar{5}$.3)	*w*
(14.4.1$\bar{8}$.3)	*w*	(11.10.2$\bar{1}$.3)	*w*	(22.2.2$\bar{4}$.3)	*m*	(26.0.2$\bar{6}$.3)	*vw*
(42$\bar{6}$1)	*w*	(7.7.1$\bar{4}$.2)	*w*	(71$\bar{8}$1)	*m*	(23.3.2$\bar{6}$.3)	*vw*
(7.5.1$\bar{2}$.2)	*vw*	(21.1.2$\bar{2}$.3)	*m*	(20.4.2$\bar{4}$.3)	*m*	(17.9.2$\bar{6}$.3)	*vvw*
(33$\bar{6}$1)	*vvw*	(19.3.2$\bar{2}$.3)	*w*	(19.5.2$\bar{4}$.3)	*w*	(14.12.2$\bar{6}$.3)	*vw*
(12.1.1$\bar{3}$.2)	*vw*	(18.4.2$\bar{2}$.3)	*m*	(62$\bar{8}$1)	*w*	(90$\bar{9}$1)	*w*
(5.8.1$\bar{3}$.2)	*vvw*	(16.6.2$\bar{2}$.3)	*m*	(11.5.1$\bar{6}$.2)	*m*	(81$\bar{9}$1)	*w*
(18.1.1$\bar{9}$.3)	*w*	(15.7.2$\bar{2}$.3)	*m*	(16.8.2$\bar{4}$.3)	*vw*	(15.3.1$\bar{8}$.2)	*m*
(15.4.1$\bar{9}$.3)	*vvw*	(13.9.2$\bar{2}$.3)	*w*	(53$\bar{8}$1)	*vw*	(20.7.2$\bar{7}$.3)	*vvw*
(18.2.2$\bar{0}$.3)	*w*	(12.10.2$\bar{2}$.3)	*w*	(14.10.2$\bar{4}$.3)	*vw*	(19.8.2$\bar{7}$.3)	*vvw*
(15.5.2$\bar{0}$.3)	*vvw*	(12.3.1$\bar{5}$.2)	*m*	(13.11.2$\bar{4}$.3)	*m*	(63$\bar{9}$1)	*m*
(12.8.2$\bar{0}$.3)	*vw*	*(9.6.1$\bar{5}$.2)	*m*	(44$\bar{8}$1)	*m*	(11.7.1$\bar{8}$.2)	*w*
(70$\bar{7}$1)	*w*	(23.0.2$\bar{3}$.3)	*vw*	(17.0.1$\bar{7}$.2)	*m*	(54$\bar{9}$1)	*vvw*
(20.1.2$\bar{1}$.3)	*m*	(21.2.2$\bar{3}$.3)	*vw*	(16.1.1$\bar{7}$.2)	*m*	(9.9.1$\bar{8}$.2)	*m*
(19.2.2$\bar{1}$.3)	*w*	(20.3.2$\bar{3}$.3)	*w*	(13.4.1$\bar{7}$.2)	*w*	(28.0.2$\bar{8}$.3)	*w*

For explanation of asterisk (*) see end of Table.

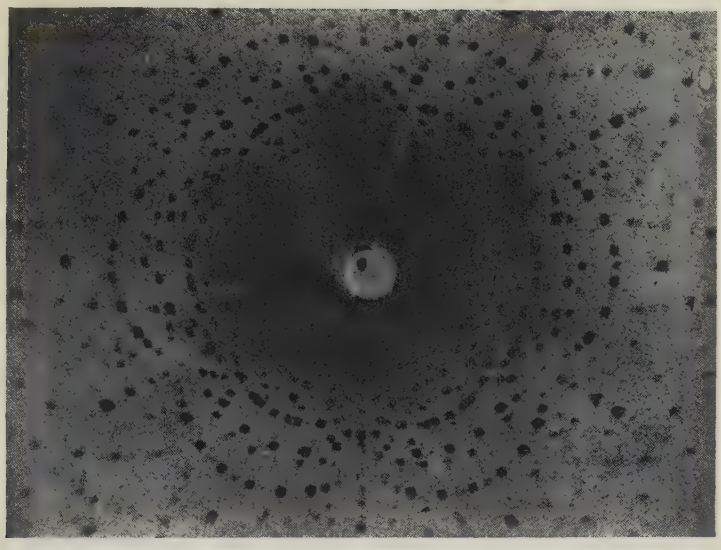

Fig. 7. Laue photograph ot nepheline specimen no. VI (crystal 2) perpendicular to the *c*-axis and with an *a*-axis horizontal.

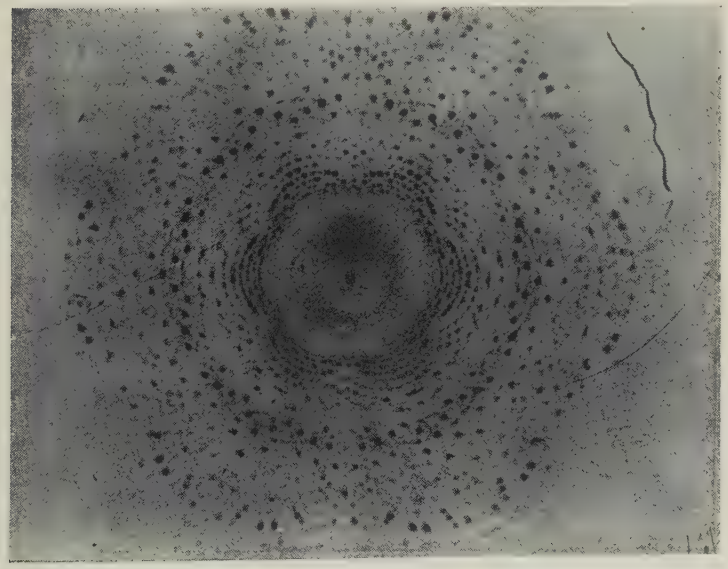

Fig. 8. Laue photograph of kaliophilite specimen no. X in same orientation as the nepheline specimen (fig. 7).

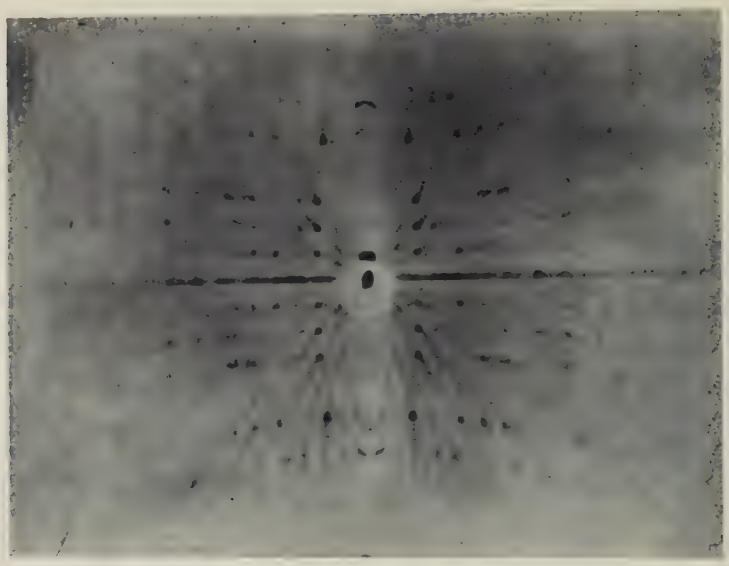

Fig. 9. Rotation photograph of nepheline specimen no. VI (crystal 2) about the *c*-axis.

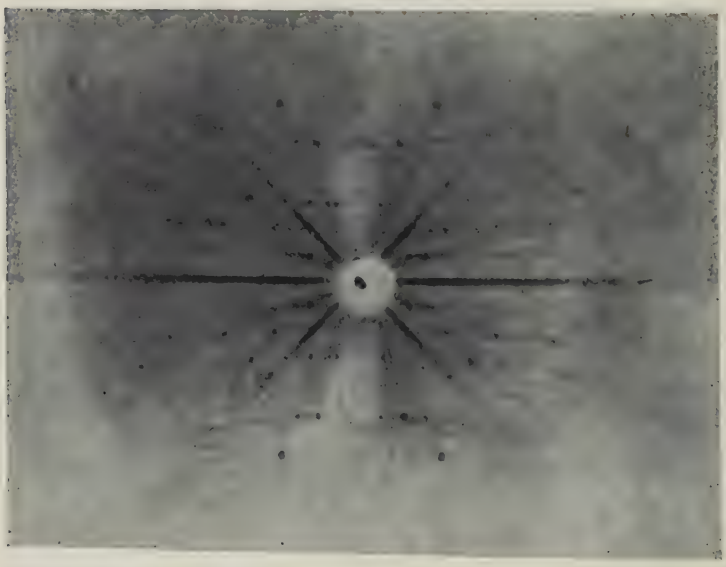

Fig. 10. Rotation photograph of kaliophilite specimen no. X about the *c*-axis.

Index.	Intensity.	Index.	Intensity.	Index.	Intensity.	Index.	Intensity.
(19.9.$\overline{28}$.3)	*w*	(32.0.$\overline{32}$.3)	*vw*	(13.0.$\overline{13}$.1)	*w*	(14.3.$\overline{17}$.1)	*w*
(15.13.$\overline{28}$.3)	*vvw*	(29.3.$\overline{32}$.3)	*vvw*	(12.1.$\overline{13}$.1)	*m*	(13.4.$\overline{17}$.1)	*w*
(19.0.$\overline{19}$.2)	*vw*	(26.6.$\overline{32}$.3)	*vw*	(11.2.$\overline{13}$.1)	*vw*	(12.5.$\overline{17}$.1)	*w*
(17.2.$\overline{19}$.2)	*s*	(20.12.$\overline{32}$.3)	*vw*	(10.3.$\overline{13}$.1)	*vw*	(11.6.$\overline{17}$.1)	*s*
(16.3.$\overline{19}$.2)	*w*	(17.15.$\overline{32}$.3)	*vw*	(19.7.$\overline{26}$.2)	*vvw*	(10.7.$\overline{17}$.1)	*w*
(15.4.$\overline{19}$.2)	*vvw*	(10.1.$\overline{11}$.1)	*vw*	(9.4.$\overline{13}$.1)	*m*	(9.8.$\overline{17}$.1)	*m*
(14.5.$\overline{19}$.2)	*m*	(19.3.$\overline{22}$.2)	*vw*	(8.5.$\overline{13}$.1)	*vw*	(18.0.$\overline{18}$.1)	*w*
(13.6.$\overline{19}$.2)	*w*	(9.2.$\overline{11}$.1)	*w*	(7.6.$\overline{13}$.1)	*m*	(17.1.$\overline{18}$.1)	*m*
(11.8.$\overline{19}$.2)	*m*	(17.5.$\overline{22}$.2)	*w*	(13.13.$\overline{26}$.2)	*m*	(16.2.$\overline{18}$.1)	*vw*
(29.0.$\overline{29}$.3)	*vw*	(8.3.$\overline{11}$.1)	*w*	(18.9.$\overline{27}$.2)	*vvw*	(15.3.$\overline{18}$.1)	*w*
(27.2.$\overline{29}$.3)	*vvw*	(7.4.$\overline{11}$.1)	*s*	(16.11.$\overline{27}$.2)	*vvw*	(14.4.$\overline{18}$.1)	*ms*
(24.5.$\overline{29}$.3)	*w*	*(6.5.$\overline{11}$.1)	*ms*	(15.12.$\overline{27}$.2)	*w*	(13.5.$\overline{18}$.1)	*m*
(23.6.$\overline{29}$.3)	*vvw*	(11.11.$\overline{22}$.2)	*w*	(14.0.$\overline{14}$.1)	*w*	(11.7.$\overline{18}$.1)	*w*
(20.9.$\overline{29}$.3)	*w*	(22.12.$\overline{34}$.3)	*vw*	(13.1.$\overline{14}$.1)	*w*	(10.8.$\overline{18}$.1)	*m*
(15.14.$\overline{29}$.3)	*vw*	(23.0.$\overline{23}$.2)	*vw*	(12.2.$\overline{14}$.1)	*w*	(9.9.$\overline{18}$.1)	*vw*
(10.0.$\overline{10}$.1)	*vw*	(22.1.$\overline{23}$.2)	*w*	(11.3.$\overline{14}$.1)	*w*	(18.1.$\overline{19}$.1)	*w*
(19.1.$\overline{20}$.2)	*w*	(21.2.$\overline{23}$.2)	*vvw*	(10.4.$\overline{14}$.1)	*w*	(17.2.$\overline{19}$.1)	*vw*
*(9.1.$\overline{10}$.1)	*m*	(20.3.$\overline{23}$.2)	*vvw*	(9.5.$\overline{14}$.1)	*m*	(16.3.$\overline{19}$.1)	*vw*
(25.5.$\overline{30}$.3)	*vw*	(19.4.$\overline{23}$.2)	*vw*	(8.6.$\overline{14}$.1)	*m*	(15.4.$\overline{19}$.1)	*m*
(8.2.$\overline{10}$.1)	*vs*	(18.5.$\overline{23}$.2)	*vvw*	(7.7.$\overline{14}$.1)	*w*	(14.5.$\overline{19}$.1)	*vvw*
(15.5.$\overline{20}$.2)	*w*	(13.10.$\overline{23}$.2)	*vvw*	(15.0.$\overline{15}$.1)	*m*	(13.6.$\overline{19}$.1)	*m*
*(7.3.$\overline{10}$.1)	*w*	(12.0.$\overline{12}$.1)	*w*	(14.1.$\overline{15}$.1)	*vvw*	(12.7.$\overline{19}$.1)	*m*
(20.10.$\overline{30}$.3)	*w*	(11.1.$\overline{12}$.1)	*w*	(13.2.$\overline{15}$.1)	*vw*	(11.8.$\overline{19}$.1)	*vw*
(19.11.$\overline{30}$.3)	*w*	(21.3.$\overline{24}$.2)	*w*	(12.3.$\overline{15}$.1)	*vw*	(10.9.$\overline{19}$.1)	*m*
*(6.4.$\overline{10}$.1)	*m*	(10.2.$\overline{12}$.1)	*w*	(11.4.$\overline{15}$.1)	*w*	(17.3.$\overline{20}$.1)	*vvw*
(16.14.$\overline{30}$.3)	*vw*	(19.5.$\overline{24}$.2)	*w*	(10.5.$\overline{15}$.1)	*w*	(16.4.$\overline{20}$.1)	*vw*
(5.5.$\overline{10}$.1)	*s*	(9.3.$\overline{12}$.1)	*vw*	(9.6.$\overline{15}$.1)	*w*	(15.5.$\overline{20}$.1)	*vw*
(31.0.$\overline{31}$.3)	*vvw*	(8.4.$\overline{12}$.1)	*w*	(8.7.$\overline{15}$.1)	*s*	(14.6.$\overline{20}$.1)	*vvw*
(28.3.$\overline{31}$.3)	*vvw*	(15.9.$\overline{24}$.2)	*m*	(16.0.$\overline{16}$.1)	*w*	(12.8.$\overline{20}$.1)	*vw*
(25.6.$\overline{31}$.3)	*vw*	(7.5.$\overline{12}$.1)	*m*	(15.1.$\overline{16}$.1)	*vw*	(10.10.$\overline{20}$.1)	*vvw*
(24.7.$\overline{31}$.3)	*vw*	(6.6.$\overline{12}$.1)	*m*	(14.2.$\overline{16}$.1)	*w*	(17.4.$\overline{21}$.1)	*vw*
(22.9.$\overline{31}$.3)	*w*	(23.2.$\overline{25}$.2)	*w*	(13.3.$\overline{16}$.1)	*s*	(16.5.$\overline{21}$.1)	*w*
(21.10.$\overline{31}$.3)	*w*	(21.4.$\overline{25}$.2)	*vw*	(12.4.$\overline{16}$.1)	*s*	(14.7.$\overline{21}$.1)	*w*
(19.12.$\overline{31}$.3)	*vw*	(20.5.$\overline{25}$.2)	*w*	(11.5.$\overline{16}$.1)	*m*	(11.10.$\overline{21}$.1)	*vw*
(16.15.$\overline{31}$.3)	*vw*	(19.6.$\overline{25}$.2)	*vw*	(10.6.$\overline{16}$.1)	*m*	(21.21.$\overline{42}$.2)	*w*
(20.1.$\overline{21}$.2)	*vw*	(18.7.$\overline{25}$.2)	*vvw*	(9.7.$\overline{16}$.1)	*s*	(13.9.$\overline{22}$.1)	*w*
(19.2.$\overline{21}$.2)	*vw*	(17.8.$\overline{25}$.2)	*w*	(8.8.$\overline{16}$.1)	*w*	(12.10.$\overline{22}$.1)	*w*
(18.3.$\overline{21}$.2)	*m*	(16.9.$\overline{25}$.2)	*vvw*	(17.0.$\overline{17}$.1)	*w*	(12.11.$\overline{23}$.1)	*vvw*
(15.6.$\overline{21}$.2)	*s*	(15.10.$\overline{25}$.2)	*vvw*	(16.1.$\overline{17}$.1)	*vvw*		
(12.9.$\overline{21}$.2)	*vs*	(14.11.$\overline{25}$.2)	*vw*	(15.2.$\overline{17}$.1)	*ms*		

* Streaks due to diffracted characteristic radiation from copper and tungsten were observed superposed upon the following Laue spots:

Index.	Line.	Wave-length.	Index.	Line.	Wave-length.
(6.4.$\overline{10}$.1)	Cu–K_α	1·539 Å.	(9.1.$\overline{10}$.1) } (6.5.$\overline{11}$.1) }	W–L_{β_4}	1·299 Å.
(7.3.$\overline{10}$.1)	W–L_{α_1}	1·473	(9.6.$\overline{15}$.2)	W–L_{β_1}	1·279

Distance of crystal to plate, 3·5 cm. *s* = strong, *m* = medium, *w* = weak. *vs* = very strong, &c.

Synthetic nepheline and kaliophilite.

Before concluding this work mention must be made of the very interesting results obtained in synthesizing nepheline and kaliophilite. The possibility of preparing artificial crystals of silicates more suitable for physical measurements than natural material is of great importance to the mineralogist of the future. Bowen,[43] Eitel,[44] and others have synthesized $NaAlSiO_4$ and $KAlSiO_4$. The low-temperature products have been identified with nepheline and kaliophilite and their physical properties studied. Bowen has concluded from a thermal study of the intermediate products formed between the sodium and potassium salts that a complete range of mixed crystals exists between the two end-members, nepheline and kaliophilite. The X-ray work has already shown that the latter mineral possesses a unit cell much larger than nepheline. It is unlikely, therefore, that mixed crystals can occur at low temperatures ; in other words low-temperature potassium-rich nepheline and kaliophilite containing some sodium are not isomorphous. The smaller crystals obtained by Bowen in his work could not be distinguished optically from the two end-members. It is desirable that this work should be repeated and X-ray photographs taken of the crystals formed by melts intermediate between nepheline and kaliophilite. In connexion with this study, powder photographs of synthesized nephelines richer in potassium than the Capo di Bove nepheline and of kaliophilites rich in sodium would, if accompanied by chemical analyses of the products formed, enable a more accurate correlation between cell-size and chemical composition to be carried out than has been possible with the available naturally occurring material.

In conclusion the author finds it difficult to acknowledge adequately the assistance he has received from so many quarters. To Dr. L. J. Spencer, Keeper of Minerals, who suggested the line of attack, I am indebted for his helpful criticism and encouragement. To Sir W. H. Bragg and past and present workers of the Davy-Faraday Laboratory I am also indebted for introducing me to the elements of X-ray crystal measurements. I wish to thank Dr. W. A. Wooster for his measurements on pyro-electricity and Mr. M. H Hey, who has given me continuous assistance during the course of this work.

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An occurrence of vanadiferous nodules in the Permian beds of South Devon.

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[Read June 9, 1931; communicated by Thomas Crook, A.R.C.Sc.(Dublin), F.G.S.]

THE object of this note is to place on record an interesting occurrence of vanadiferous nodules on the coast of South Devon. I have to thank Lord Clinton, the owner of the property on which the nodules occur, for the assistance and encouragement he has given me in this matter, and Lieut.-General Sir William Furse, the Director of the Imperial Institute, for kindly arranging to have chemical analyses carried out by Miss Hilda Bennett in the Institute Laboratory. I also have to thank Mr. Thomas Crook, of the Imperial Institute, for the trouble he has taken to write up this short paper on the basis of my notes and the laboratory work done at the Institute.

The nodules referred to above are to be found in the red marls immediately underlying the Budleigh Salterton pebble bed,[1] to a depth of at least 400 feet; they are also to be seen in the red clay on the beach as waterworn specimens. On the cliff face they stand out clearly as dark cores surrounded by aureoles of greenish clay. In the natural section provided by the cliff face they are traceable for about half a mile on either side of Straight Point, with a maximum development west of the base of West Down Beacon, near Budleigh Salterton. Inland, the principal exposure is in Mr. F. E. Carter's brickfield in Withycombe Raleigh parish, about 1½ miles from the coast; and it seems not unlikely that the nodules occur over the whole area between these exposures, viz. at least 1,000 acres.

Where the nodules are found in landslips or wet ground, the aureole is no longer observable, and the nodule itself becomes a pulverulent

[1] In the Geological Survey memoir and map (Sheet 339, 1913) the Budleigh Salterton pebble bed marks the base of the Trias, and the underlying red marls are mapped as Permian. Some authors (e.g. H. B. Woodward, Geology of England and Wales, 1887, p. 235, fig. 36) have included these red marls in the Trias.

sandy ball of a sepia colour. In the white sandstones which occur interbedded with the marls, nodular sepia banding may be seen. Stored under conditions of dryness, the dark portions of the nodules develop a yellow bloom.

The nodules are small in mass in proportion to the mass of the clays in which they are embedded, but they are easily distinguishable by the bleached aureoles surrounding them. As the cliffs break away by weathering, the nodules are lost or redistributed in the beach accumulations, while new nodules are exposed. Bleached beds resembling the aureoles extend for long distances. They can be seen at Exmouth, Lympstone, Woodbury, and Exeter in one direction, and at Ottery St. Mary in Triassic beds to the east.

Fossiliferous strata, in which the fossils are now represented almost wholly by casts of molluscs, form part of the nodule-bearing beds. The position and growth of any nodule appears to have no direct connexion with the position of any fossil. The fossiliferous strata have so far been observed to have a thickness of about fifty feet, but they may be much thicker.

The nodules are often roughly spherical in shape, with dark surface ribs, and in appearance often look like the crowns of sea lilies. When broken they show a roughly concentric structure, ill-defined blackish shells alternating with shells of light-coloured material. Radiating planes of the blackish material traverse the shells and stand out as ribs on some of the nodules. The nodules are of various sizes from finely disseminated bleached spots to large balls. The largest so far found was spherical in shape; it measured eight inches in diameter and weighed twenty-one pounds.

A specimen (fig. 1) examined at the Imperial Institute was spherical in shape and about four inches in diameter. When cut hemispherically it showed a blackish nucleus followed by a shell of light-coloured material. This was succeeded by a shell about half-an-inch thick of blackish material, from which bands of roughly the same thickness radiated outwards, appearing as ribs on the surface.

Two samples were prepared from this specimen, one of the light-coloured and one of the blackish material, and these gave the following analyses (p. 612).

The analyses show that the material of the nodule consists essentially of indurated siliceous clayey material. The light-coloured portions contain appreciable amounts of lime and carbon dioxide as compared with the blackish portions, these together with silica

making up most of the defect of vanadic oxide shown by the light-coloured as compared with the blackish material. No appreciable amounts of lead, copper, sulphur, or phosphorus appear to be present

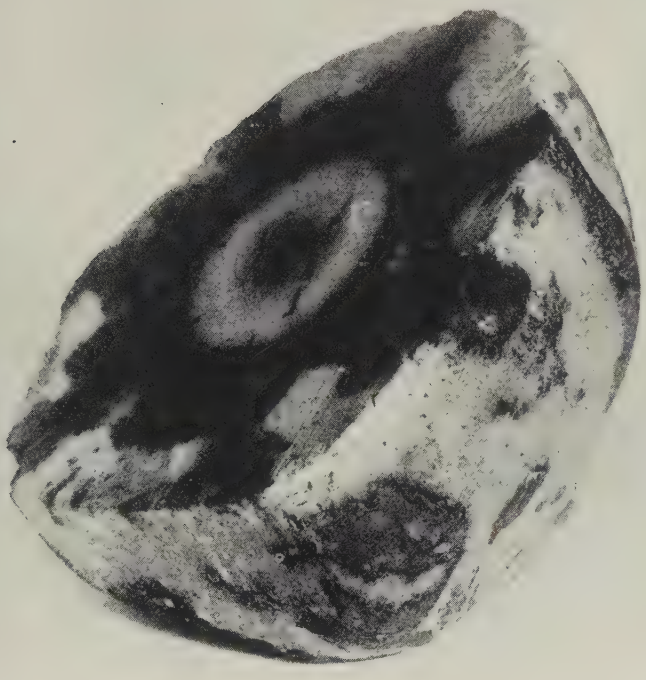

Fig. 1. Vanadiferous nodule (sawn in half) from the shore west of Budleigh Salterton, South Devon. (Actual size.)

in the nodule examined, and the comparative percentages of iron oxide, magnesia, potash, and soda in the two different portions analysed do not indicate a state of combination with the vanadic oxide. The lime, which is concentrated in the light-coloured portion of the nodule, is largely if not wholly present as calcium carbonate. It would therefore appear that the vanadium is present as an impregnation of vanadium oxide, possibly hydrated.

Analyses of Vanadiferous nodule.

(By Miss Hilda Bennett, M.A., B.Sc., A.I.C.)

		Blackish portion.	Light-coloured portion.
Silica	SiO_2	51·86	59·05
Titanium dioxide...	TiO_2	0·71	0·88
Alumina	Al_2O_3	14·16	15·14
Vanadium as pentoxide	V_2O_5	13·96	1·91
Iron as ferric oxide	Fe_2O_3	2·32	2·85
Cobalt and nickel oxides ...	CoO, NiO	0·18	0·06
Manganous oxide...	MnO	trace	not detected
Lead oxide	PbO	not detected	—
Copper oxide	CuO	trace	—
Magnesia	MgO	2·85	2·47
Lime	CaO	0·70	3·06
Soda	Na_2O	0·56	0·88
Potash	K_2O	4·60	4·86
Carbon dioxide	CO_2	0·38	2·54
Sulphur (soluble in acid) ...	S	0·08	—
Combined water	H_2O+	4·16	3·58
Moisture	H_2O-	3·98	2·16
		100·50	99·44

The red clay surrounding the nodules when digested with strong hydrochloric acid leaves a large white residue, and the solution was found to contain, besides iron, V_2O_5 0·17% of the mass of the clay. This determination was made by Hillebrand's volumetric method by Mr. M. H. Hey in the Mineral Department of the British Museum on material collected by Dr. L. J. Spencer from the cliffs west of Budleigh Salterton. The material so tested was taken from a specimen showing a green-black nodule $1\frac{1}{2}$ cm. in diameter surrounded by a pale-green halo $4\frac{3}{4}$ cm. across. The bleached circular area shows a sharp line of demarcation from the surrounding red clay, the contrast being very striking. The mass of indurated red clay is speckled through with minute pale-green circular areas usually less than 1 mm. in diameter.

Occurrences of vanadiferous impregnations of a closely similar character have been recorded from the Permian shales at Ölsnitz and other localities in Saxony by R. Schreiter.[1] The dark material on analysis gave V_2O_4 14·93, V_2O_3 1·42, FeO 1·60, H_2O 8 – 9 % together

[1] R. Schreiter, Vanadiumoxyde im sächsischen Rotliegenden und ihre Bleichungswirkung. Jahrb. Berg- und Hüttenw. Sachsen, 1927, vol. 101, pp. A 49–A 69. See also Centr. Min., Abt. A, 1925, pp. 143, 214, 242. [Min. Abstr., vol. 3, p. 554.]

with silica, alumina, &c.; and the pale-green bleached aureoles gave V_2O_5 0·1 to 2·4 %; whilst the surrounding red shale contains V_2O_5 traces to 0·1 %.

The bleached patches, often concentrically zoned with the dark material, examined by Schreiter, were attributed by him to the reduction of iron in the presence of the lower oxides of vanadium. Other explanations that have been invoked to account for the concentric banding are rhythmic precipitation in a colloidal medium, and radioactivity effects. In this connexion it should be mentioned that the South Devon nodules are very slightly radioactive, but no thorium or other rare-earths were found on analysis, and the percentage of uranium oxide (U_3O_8) in one nodule examined amounted to only 0·07 per cent. of the whole nodule. The effect on a photographic plate showed a concentric arrangement, and the radioactive portions appeared to be at the margins of the light and dark material.

This occurrence of vanadiferous nodules is of some economic interest, as vanadium minerals are of sparse distribution. A considerable amount of the nodules could no doubt be obtained as a by-product in working the clays in which they occur, which clays are used for brick-making. The occurrence is therefore worth investigating as one of possible emergency value from the economic standpoint as a source of vanadium. In any such investigation that may be carried out, attention should also be given to the Exeter shales, the nodules from which exhibit concentric banding in a still greater degree than those shown by the nodules occurring in the marls.

Twelfth list of new mineral names.[1]

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Achromaite. F. Kretschmer, 1918. Jahrb. Geol. Reichsanstalt, Wien, vol. 67 (for 1917), p. 115 (Achromait). A variety of hornblende, perfectly colourless in micro-sections, forming a constituent of weigelite (hornblende-peridotite) from Weigelsberg, Moravia. Named from *ἀχρώματος*, colourless.

Alkali-beryl. S. L. Penfield, 1884. Amer. Journ. Sci., ser 3, vol. 28, p. 25 ('alkalies in beryl'). A. Lacroix, Bull. Soc. Franç. Min., 1908, vol. 31, p. 236 ('Béryl riche en alcalis'). Certain beryls contain appreciable amounts of alkalis: Li_2O up to 2·00 %, Na_2O 4·22 %, K_2O 2·25 %, Cs_2O 4·56 %, Rb_2O 1·34 %. *See* Caesium-beryl. [M.A. **1**–76, 446; **3**–448; **4**–138, 315.]

Alkali-hastingsite, Alkali-ferrohastingsite, Alkali-femaghastingsite. M. Billings, 1928. *See* Ferrohastingsite.

Allodelphite. P. Quensel and H. von Eckermann, 1931. Geol. För. Förh. Stockholm, vol. 52 (for 1930), p. 639 (Allodelphite). Hydrous silico-arsenite of manganese, $5MnO.2Mn_2O_3.As_2O_3.SiO_2.5H_2O$ or $MnO.(Mn_2,As_2,MnSi)O_3.H_2O$, as red-brown crystals, probably orthorhombic, from Långban, Sweden. Named from *ἄλλος*, other, and *ἀδελφός*, brother, on account of its relationship to synadelphite. [M.A. **4**–496.]

Almashite. G. Murgoci, 1924. Les ambres roumains, Correspondance économique roumaine, Bulletin officiel, Ministère de l'Industrie et du Commerce, Bucarest, 1924, vol. 6, no. 6, pp. 10, 16. A. P.

[1] Previous lists of this series have been given at the ends of vols. 11–21 (1897–1928) of this Magazine. The 1,506 names in the first ten lists are included in one alphabetical arrangement in the General Index (1926) to vols. 11–20 (1895–1925). References to 'Mineralogical Abstracts' are given in the form [M.A. **4**–496].

Iancoulesco, Les richesses minières de la nouvelle Roumanie, Paris, 1928, p. 229. C. Doelter, Handbuch d. Mineralchemie, 1931, vol. 4, pt. 3, p. 935 (Almaschit). Green (almashite I) and black (almashite II) varieties of amber, differing from romanite, from the Almaș (Almash) valley near Piatra in Moldavia. The green variety contains C 82·15, H 10·94, O 2·57, S 0·33, ash 3·51, and the black C 79·45, H 10·23, O 3·00, S 1·40, ash 5·52. Named from the locality. [M.A. **4**–297.]

Ameletite. P. Marshall, 1929. Min. Mag., vol. 22, p. 174. Silicate with chloride of aluminium and sodium, approximate formula $9Na_2O.6Al_2O_3.12SiO_2.\frac{1}{2}NaCl$, as minute hexagonal crystals in phonolite from Dunedin, New Zealand. Named from ἀμελής, neglected, because the mineral had long been unrecognized.

Ammonioborite. W. T. Schaller, 1931. Amer. Min., vol. 16, p. 114. Hydrous borate of ammonium, $(NH_4)_2O.5B_2O_3.5H_2O$, differing optically from larderellite, with which it occurs at Laderello, Toscana. Named from the composition.

Anorthite-haüyne. L. H. Borgström, 1930. Zeits. Krist., vol. 74, p. 119 (Anorthithauyn). A hypothetical molecule, $3CaAl_2Si_2O_8.2CaSO_4$, corresponding with haüyne ($3Na_2Al_2Si_2O_8.2CaSO_4$), to explain the composition of the sodalite group. Part of this molecule has the composition of anorthite, hence the name. [M.A. **4**–355.]

Anorthoclase-sanidine. *See* Sanidine-anorthoclase.

Antamokite. A. D. Alvir, 1928. Engin. & Mining Journ. New York, 1928, vol. 125, p. 616; Amer. Min., 1928, vol. 13, p. 491; Philippine Journ. Sci., 1930, vol. 41, p. 137. Telluride of gold with trace of silver, differing from calaverite in its micro-chemical reactions. Named from the locality, Antamok, Mountain Province, Philippine Islands. [M.A. **4**–250.]

Arandisite. F. C. Partridge, 1930. Trans. Geol. Soc. S. Africa, vol. 32 (for 1929), p. 171. T. W. Gevers, ibid., p. 169. Hydrous basic silicate of tin, $3SnSiO_4.2SnO_2.4H_2O$, as apple-green masses with cassiterite and quartz from near Arandis, Swakopmund district, South-West Africa. Named from the locality. [M.A. **4**–248.]

Arsenoklasite. G. Aminoff, 1931. Kungl. Svenska Vetenskapsakad. Handl., ser. 3, vol. 9, no. 5, p. 52 (Arsenoklasite). Basic

arsenate of manganese, $Mn_3(AsO_4)_2.2Mn(OH)_2$, as red orthorhombic cleavages from Långban, Sweden. Named from *ἀρσενικόν*, orpiment, and *κλάσις*, breaking. [M.A. **4**–496.]

Arsenomarcasite. W. T. Schaller, 1930. Amer. Min., vol. 15, p. 567. Suggested as a more suitable name for arsenopyrite, the mineral being orthorhombic and not cubic. Synonym of mispickel.

Bayerite. R. Fricke, 1928. Zeits. Anorg. Chem., 1928, vol. 175, p. 252; 1929, vol. 179, p. 287 (Bayerit). G. F. Hüttig and O. Kostelitz, ibid., 1930, vol. 187, p. 4. An artificial form of aluminium hydroxide, $Al(OH)_3$, metastable with respect to gibbsite, obtained in the K. J. Bayer process for the purification of bauxite. [M.A. **4**–30, 169, 305.]

Beryllium-vesuvianite, Be-vesuvianite. C. Palache and L. H. Bauer, 1930. Amer. Min., vol. 15, p. 31 ; L. H. Bauer, ibid., p. 199. Idocrase from Franklin Furnace, New Jersey, containing BeO 9·20 %. [M.A. **4**–329.]

Bialite. H. Buttgenbach, 1929. Ann. Soc. Géol. Belgique, Publ. Congo Belge, vol. 51 (for 1927–8), p. c 117. Hydrous phosphate of aluminium, magnesium, and calcium, as white orthorhombic needles, from Belgian Congo. Perhaps a magnesian variety of tavistockite. Named after Captain Lucien Bia (1852–1892), a pioneer explorer in Belgian Congo. [M.A. **4**–148.]

Bianchite. C. Andreatta, 1930. Atti (Rend.) R. Accad. Lincei, Cl. Sci. fis. mat. nat. Roma, ser. 6, vol. 11, p. 760. Abstract in Chem. Zentr., 1930, vol. 2, p. 1355, gives the name incorrectly as Biankit. Hydrous double sulphate of zinc and iron, $FeZn_2(SO_4)_3.18H_2O$, as a white crystalline crust (probably monoclinic) from Raibl, Italy (formerly in Carniola). Named after Prof. Angelo Bianchi, of Padova. [M.A. **4**–341.]

Bismutotantalite. E. J. Wayland and L. J. Spencer, 1929. Min. Mag., vol. 22, p. 185. Tantalate (and niobate) of bismuth, $Bi_2O_3.Ta_2O_5$, as black orthorhombic crystals from Uganda. Named from the chemical composition on analogy with stibiotantalite. *See* Ugandite.

Blomstrandinite. A. N. Winchell, 1927. Elements of optical mineralogy, 2nd edit., pt. 2, p. 161. The same as Blomstrandine (of W. C. Brøgger, 1906 ; 4th List) with a double termination. Not the

Blomstrandite of G. Lindström, 1874, also named after C. W. Blomstrand (1826–97).

Botesite. K. Vrba, 1897. Ottův Slovník Naučný [Otto's Encyclopaedia], Praha, 1897, vol. 11, p. 230. F. Slavík in C. Doelter's Handbuch d. Mineralchemie, 1926, vol. 4, pt. 1, p. 868 (Botesit). Synonym of Hessite. The name was used by K. Vrba on MS. labels in the University mineral collection at Praha in 1882 : it is unknown in Hungarian literature. Named from the locality, Mt. Botes, Transylvania.

Buszite. E. Steinwachs, 1929. Centr. Min., Abt. A, 1929, p. 202 (Buszit). From qualitative tests on a small amount of material, apparently a silicate of the rare-earths neodymium, praseodymium, erbium, and europium. A single small ditrigonal bipyramidal crystal, has been found in South-West Africa. Named after Prof. Karl Heinrich Emil Georg Busz [1863–1930], of Münster, Westphalia. [M.A. **4**–149.]

Caesium-beryl. S. L. Penfield, 1888. Amer. Journ. Sci., ser. 3, vol. 36, p. 317 ('the cæsium beryl of Norway, Maine'). A variety of alkali-beryl (q v.) containing Cs_2O up to 4·56 %, usually as pink crystals of tabular habit. Afterwards named vorobyevite (V. I. Vernadsky, 1908 ; 5th List) and morganite (G. F. Kunz, 1911 ; 6th List). Compare also rosterite (F. Zambonini and V. Caglioti, 1928 ; M.A. **4**–138). [M.A. **1**–76 ; **3**–448 ; **4**–96, 315.]

Calciotantalite. E. S. Simpson, 1907. Rep. Australian Assoc. Adv. Sci., vol. 11. p. 452 ; Amer. Min., 1928, vol. 13, p. 465. A calciferous (CaO 7·78 %) tantalite from Western Australia. [M.A. **4**–184.]

Clarkeite. C. S. Ross, E. P. Henderson, and E. Posnjak, 1931. Amer. Min., vol. 16, pp. 114, 213. Hydrous uranate of sodium and lead, $RO.3UO_3.3H_2O$, dark brown with waxy lustre, forming with gummite a zone of alteration around uraninite from North Carolina. Named after Prof. Frank Wigglesworth Clarke (1847–1931), of Washington, D. C. [M.A. **4**–498.]

Cobaltsmithsonite. G. A. Bilibin, 1927. Mém. Soc. Russ. Min., ser. 2, vol. 56, p. 34 (Кобальтсмитсонит), p. 36 (Cobaltsmithsonite). The cobaltiferous smithsonite (CoO 10·25 %) from Boleo, Lower California, Mexico, analysed by C. H. Warren in 1898.

Collieite. R. Brown, 1927. Trans. Dumfriesshire & Galloway Nat. Hist. Antiq. Soc., ser. 3, vol. 13 (for 1925–26), p. 72. The calcium vanado-pyromorphite from Leadhills, Scotland, analysed in 1889 by Prof. John Norman Collie, F.R.S., of London, after whom it is named. [M.A. **4**–468.]

Cooperite. F. Wartenweiler, 1928. In R. A. Cooper, Journ. Chem. Metall. Mining Soc. South Africa, 1928, vol. 28, p. 283. H. Schneiderhöhn, Centr. Min., Abt. A, 1929, p. 193; Chem. Erde, 1929, vol. 4, pp. 268, 275. P. A. Wagner, The platinum deposits and mines of South Africa, 1929, pp. 12, 18, 226, 237. H. R. Adam, Trans. Geol. Soc. South Africa, 1931, vol. 33 (for 1930), p. 104. Platinum sulphide, PtS_2, as minute pyritohedral-cubic crystals isomorphous with sperrylite, occurring in the platiniferous norite of the Bushveld, Transvaal. Named after R. A. Cooper, of Johannesburg, by whom the mineral was first described (loc. cit., 1928, p. 281). Not the cooperite of —Adam, 1869. Also trade-name for an alloy of nickel, zirconium, tungsten, &c., used for cutting-tools. [M.A. **4**–10, 145, 149, 500.]

Dehrnite. E. S. Larsen and E. V. Shannon, 1930. Amer. Min., vol. 15, pp. 303, 324. Hydrous phosphate of calcium and sodium, perhaps $7CaO.Na_2O.2P_2O_5.H_2O$ for soda-dehrnite from Dehrn, Nassau (p. 305), or $14CaO.K_2O.Na_2O.4P_2O_5.2H_2O.CO_2$ from Utah (p. 325), as white crystalline (hexagonal) crusts. Named from the locality. [M.A. **4**–342, 344.]

Deltaite. E. S. Larsen and E. V. Shannon, 1930. Amer. Min., vol. 15, p. 321. Hydrous phosphate of calcium and aluminium, $8CaO.5Al_2O_3.4P_2O_5.14H_2O$, as a constituent of variscite nodules from Utah. Named from the Δ-like (trigonal) form of the mineral in intimate intergrowth with pseudowavellite [M.A. **4**-344.]

Dennisonite. E. S. Larsen and E. V. Shannon, 1930. Amer. Min., vol. 15, p. 322. Hydrous phosphate of calcium and aluminium, $6CaO.Al_2O_3.2P_2O_5.5H_2O$, as white crusts (hexagonal?) in variscite nodules from Utah. Named after 'J. M. Dennison who first described wardite', i.e. John Mason Davison (1840 1915), of the University of Rochester, New York. [M.A. **4**–344.]

Dickite. C. S. Ross and P. F. Kerr, 1930. Amer. Min., vol. 15, p. 34; Journ. Amer. Ceramic Soc., 1930, vol. 13, p. 151; Prof. Paper U.S. Geol. Survey, 1931, no. 165–E, p. 157. The crystallized

kaolin mineral, $Al_2O_3.2SiO_2.2H_2O$ from Anglesey, distinguished by its optical characters from both kaolinite and nacrite. Named after Allan Brugh Dick (1833–1926), of London, who described the mineral as kaolinite in 1888. [M.A. **4**–247.]

Elbrussite. I. J. Mickey, 1930. Centr. Min., Abt. A, 1930, p. 300 (Elbrussit). Hydrous silicate of aluminium, ferric and ferrous iron, with some magnesia and alkalis, belonging to the nontronite-beidellite group. Named from the locality, Mt. Elbrus (Эльбрус), Caucasus. [M.A. **4**–342.]

Emildine. J. S. van der Lingen, 1928. South African Journ. Sci., vol. 25, pp. 12, 15 (Emildine), p. 13 (Emaldine), p. 14 (Emilite). A spessartine garnet from the granites of South-West Africa, found on spectroscopic analysis to contain yttrium, but no chromium and little or no magnesium (cf. erinadine). Named after the author's son Emil, the *d* in the termination being from false analogy with almandine. [M.A. **4**–83.]

Englishite. E. S. Larsen and E. V. Shannon, 1930. Amer. Min., vol. 15, p. 328. Hydrous phosphate of calcium, aluminium, and potassium, $4CaO.K_2O.4Al_2O_3.4P_2O_5.14H_2O$, as thin colourless layers in variscite nodules from Utah; probably orthorhombic, with micaceous cleavage. Named after Mr. George Letchworth English, of Rochester, New York. [M.A. **4**–344.]

Erinadine. J. S. van der Lingen, 1928. South African Journ. Sci., vol. 25, p. 13. A metamorphic garnet from the granite-slate contact in the Cape Peninsula, found on spectroscopic analysis to contain yttrium together with chromium and magnesium (cf. emildine). Named after the author's daughter Erina, the *d* in the termination being from false analogy with almandine. The same author had earlier used the preoccupied name erinite (Erinit: Centr. Min., Abt. A, 1926, p. 182) in the belief that the mineral contained the hypothetical radioactive element 'hibernium'. [M.A. **4**–83, **2**–162.]

Femaghastingsite. M. Billings, 1928. *See* Ferrohastingsite.

Ferrohastingsite. M. Billings, 1928. Amer. Min., vol. 13, p. 287. The original hastingsite, from Hastings Co., Ontario, in which ferrous oxide predominates largely over magnesia. In Magnesiohastingsite

magnesia predominates, and intermediate members of the group are distinguished as Femaghastingsite (p. 292). Other varieties containing more alkalis are distinguished as Alkali-hastingsite, including Alkali-ferrohastingsite and Alkali-femaghastingsite (p. 294). [M.A. **4**–39.]

Ferroschallerite. L. H. Bauer and H. Berman, 1930. Amer. Min., vol. 15, p. 345. A variety of schallerite (10th List) in which the manganese is partly replaced by iron (FeO 17·12 %). [M.A. **4**–345.]

Fersmanite. A. N. Labuntzov, 1929. Compt. Rend. Acad. Sci., URSS, Leningrad, Ser. A, 1929, p. 296 (Ферсманит, fersmanite). Titano-silicate and fluoride of calcium and sodium, $4RTiO_3.2R_2Si(O,F)_2.SiO_2$, as monoclinic crystals resembling sphene from nepheline-syenite in the Kola peninsula. Named after Prof. Aleksandr Evgenievich Fersman (Александр Евгеніевич Ферсман), of Leningrad. [M.A. **4**–246.]

Fervanite. E. P. Henderson and F. L. Hess, 1931. Amer. Min., vol. 16, p. 119. F. L. Hess and E. P. Henderson, ibid., p. 273. Hydrous vanadate of iron, $2Fe_2O_3.2V_2O_5.5H_2O$, as a fibrous (monoclinic?) yellow mineral in sandstone from Colorado and Utah. Named from the composition. [M.A. **4**–498.]

Fülöppite. I. de Finály and S. Koch, 1929. Min. Mag., vol. 22, p. 179; Magyar Tudom. Akad. Mat. Természett. Értesítő, 1929, vol. 46, pp. 663, 673 (fülöppit). Lead sulphantimonite, $2PbS.3Sb_2S_3$, as monoclinic crystals; an acid member of the plagionite-semseyite group. From Nagybánya, Hungary (= Baia Mare, Romania). Named after Dr. B. Fülöpp, a Hungarian mineral collector. [M.A. **4**–244.]

Gordonite. E. S. Larsen and E. V. Shannon, 1930. Amer. Min., vol. 15, p. 331. Hydrous phosphate of magnesium and aluminium, $MgO.Al_2O_3.P_2O_5.9H_2O$, as colourless monoclinic crystals in variscite nodules from Utah. Related to paravauxite [$FeO.Al_2O_3.P_2O_5.5H_2O$]. Named after 'Mr. S. L. Gordon who first described paravauxite', i.e. Mr. Samuel George Gordon, of the Academy of Natural Sciences of Philadelphia. [M.A. **4**–344.]

Gudmundite. K. Johansson, 1928. Zeits. Krist., vol. 68, p. 87 (Gudmundit). Sulphantimonide of iron, FeSbS, as orthorhombic crystals isomorphous with and resembling mispickel [FeAsS], from Gudmundstorp, near Sala, Sweden. Named from the locality. [M.A. **4**–12.]

Haematophanite. K. Johansson, 1928. Zeits. Krist., vol. 68, p. 102 (Hämatophanit). Oxychloride of lead and iron, $Pb(Cl,OH)_2$. $4PbO.2Fe_2O_3$, as reddish-brown tetragonal scales, from Jakobsberg, Sweden. Apparently named (from *φαίνεσθαι*, to appear) because of the superficial resemblance to haematite. [M.A. **4**–13.]

Iosene. Brit. Chem. Abstr. A, 1929, p. 1429; and Neues Jahrb. Min. Ref. I, 1930, p. 126 (Iosen); from A. Soltys, Sitzungsber. Akad. Wiss. Wien, Math.-naturw. Kl., Abt. II b, 1929, vol. 138 (Supplement), p. 175 = Monatshefte Chem. Wien, vol. 53–54, p. 175 (Josen). Error for Josen [10th List], a synonym of hartite. The name Josen was used in manuscript by the late Prof. K. B. Hofmann, of Graz, after his wife Josepha, and was first published by F. Machatschki in 1924. [M.A. **2**–474, **4**–349.]

Kanbaraite. H. Isobe and T. Watanabe, 1930. Bull. Inst. Phys. & Chem. Research, vol. 9, p. 440; Sci. Papers Inst. Phys. & Chem. Research, Tokyo, 1930, vol. 13, Abstracts p. 40. A hexagonal acid clay (Kanbara clay) from Japan with the composition $H_4Al_2MgSi_6O_{18}$. xH_2O is called 'kanbaraite A', and the dehydrated (at 800° C.) cubic form $H_4Al_2MgSi_6O_{18}$ is called 'kanbaraite B'. [M.A. **4**–501.]

Khakassite. G. A. Bilibin, 1926. Zap. Ross. Min. Obshch. (Mém. Soc. Russ. Min.), 1928, ser. 2, vol. 57, p. 307 (Хакассит). This name, which appeared in the title of the paper when read in 1926, was afterwards replaced by Alumohydrocalcite (11th List). Named from the locality, Khakassky district in Siberia.

Kilbreckanite. R. Griffith, Catalogue of the several localities in Ireland where mines or metalliferous indications have hitherto been discovered, 1854, p. 2 (reprinted, Dublin, 1884); G. H. Kinahan, Economic geology of Ireland, Journ. Roy. Geol. Soc. Ireland, 1889, vol. 8, p. 14. Another spelling of Kilbrickenite (J. Apjohn, 1841) from the Monanoe or Kilbreckan lead mine, near Quin, Co. Clare, Ireland. A synonym of Geocronite.

Klebelsbergite. V. Zsivny, 1929. Magyar Tudom. Akad. Mat. Természett. Értesítő, Budapest, vol. 46, p. 19 (Klebelsbergit). Hydrous basic antimony sulphate, as monoclinic needles on stibnite from Felsőbánya, Hungary (= Baia Sprie, Romania). Named after Count Kuno Klebelsberg, Hungarian Minister of Education. [M.A. **4**–150.]

Klinoolivin. E. Dittler, 1929. Sitzungsber. Akad. Wiss. Wien, Math.-naturw. Kl., Abt. I, vol. 138, p. 411. A synonym of the monoclinic titanclinohumite. Orthorhombic titanolivine has been prepared artificially, but is not known as a mineral. F. Machatschki, Centr. Min., Abt. A, 1930, p. 200, rightly regards the name as superfluous. [M.A. **4**–309.]

Kramerite. W. T. Schaller, 1930. Prof. Paper U. S. Geol. Survey, no. 158–I, p. 139. The name first appeared, but without description, in Amer. Min., 1928, vol. 13, p. 453. Hydrous borate of sodium and calcium, $Na_2O.2CaO.5B_2O_3.10H_2O$ (i.e. the same as ulexite with $10H_2O$ instead of $16H_2O$), as rosettes of monoclinic prisms in the borate deposits of the Kramer district, Kern Co., California. Named from the locality. Identical with Probertite (q.v.). [M.A. **4**–245.]

Krausite. W. F. Foshag, 1931. Amer. Min., vol. 16, pp. 115, 352. Hydrous sulphate of iron and potassium, $K_2SO_4.Fe_2(SO_4)_3.2H_2O$, as yellowish-green monoclinic crystals from California. Named after Prof. Edward Henry Kraus, of the University of Michigan.

Landesite. H. Berman and F. A. Gonyer, 1930. Amer. Min., vol. 15, p. 384. Hydrous phosphate of ferric oxide and manganous oxide, $3Fe_2O_3.20MnO.8P_2O_5.27H_2O$, as an alteration product of reddingite, from Maine, U.S.A. Named after Prof. Kenneth K. Landes, of the University of Kansas. [M.A. **4**–344.]

Larnite. C. E. Tilley, 1929. Min. Mag., vol. 22, p. 77. Calcium orthosilicate, Ca_2SiO_4, as grains (monoclinic) in a chalk-dolerite contact-rock. Identical with the artificial α-Ca_2SiO_4. Named from the locality, Larne, Co. Antrim, Ireland.

Lausenite. G. M. Butler, 1928. Amer. Min., vol. 13, p. 594. To replace the name Rogersite (C. Lausen, 1928 ; 11th List) which was preoccupied (J. L. Smith, 1877). Named after Mr. Carl Lausen, of the Arizona Bureau of Mines. [M.A. **4**–12.]

Lehiite. E. S. Larsen and E. V. Shannon, 1930. Amer. Min., vol. 15, p. 329. Hydrous phosphate of calcium, aluminium, and alkalis, $5CaO.(Na,K)_2O.4Al_2O_3.4P_2O_5.12H_2O$, as white crusts (monoclinic ?) in variscite nodules from near Lehi, Utah. Named from the locality. [M.A. **4**–344.]

Lessingite. V. A. Zilbermintz, 1929. Compt. Rend. Acad. Sci. URSS, Leningrad, Ser. A, 1929, p. 55 (lessingite, лессингит).

Hydrous silicate of cerium and calcium, $H_2Ca_2Ce_4Si_3O_{15}$, found as cherry-red glassy pebbles in the gold-washings of the Kyshtymsk district, Ural. Named after Prof. Frantz Yulievich Levinson-Lessing (Франц Юліевич Левинсон-Лессинг), of Leningrad. [M.A. **4**-150.]

Lewistonite. E. S. Larsen and E. V. Shannon, 1930. Amer. Min., vol. 15, p. 326. Hydrous phosphate of calcium and alkalis, near $15CaO.(K,Na)_2O.4P_2O_5.8H_2O$, as minute hexagonal prisms in variscite nodules from Utah. Named after the locality, Lewiston, Utah. [M.A. **4**–344.]

Liparite. This well-known rock-name was earlier applied to three distinct mineral-species—chrysocolla, fluorite, and talc.

(1) F. Casoria, 1846. Atti della 7ª adunanza degli Scienziati Italiani, Napoli, vol. 7 (for 1845), pt. 2, p. 1156. For a hydrous copper silicate from the island of Lipari the formula was deduced as $2CuO.3SiO_2.4\frac{1}{2}H_2O$, but G. Carobbi, Gazz. Chim. Ital., 1928, vol. 58, p. 801, proves the identity of the mineral with chrysocolla. Named from the locality. [M.A. **4**–139.]

(2) E. F. Glocker 1847. Generum et specierum mineralium synopsis, p. 282 (Liparites, Liparit). Synonym of fluorite. From *λιπαρός*, splendent.

(3) A. E. Arppe, 1858. Acta Soc. Sci. Fennicae, vol. 5, p. 476 (Jerntalk, Liparit). A ferruginous talc (Fe_2O_3 9·25 %) from Finland. From *λιπαρός*, oily.

(4) J. Roth, 1861. Die Gesteins-Analysen, p. xxxiv (Liparit). An acid volcanic rock from the Lipari Islands. Synonym of rhyolite of F. von Richthofen, Jahrb. Geol. Reichsanstalt, Wien, 1861, vol. 11 (for 1860), p. 156 (Rhyolith). Named from the locality.

Lithium-amphibole. C. Palache, S. C. Davidson, and E. A. Goranson, 1930. Amer. Min., vol. 15, p. 292. The molecule $Li_2(Mg,Fe)_3Al_2Si_8O_{22}(OH)_2$, or an amphibole containing this in large amount, such as holmquistite or Lithionglaukophan (7th List). [M.A. **4**–526.]

Loseyite. L. H. Bauer and H. Berman, 1929, Amer. Min., vol. 14, pp. 103, 150. Basic carbonate of manganese and zinc, $2RCO_3.5R(OH)_2$, as bluish-white monoclinic needles from Franklin Furnace, New Jersey. Named after Samuel R. Losey (1833 ?–1906 ?), a local collector. [M.A. **4**–151.]

Maghemite. P. A. Wagner, 1927. Econ. Geol., vol. 22, p. 846; Mem. Geol. Survey South Africa, 1928, no. 26, pp. 18, 29. A contraction of magnetite and hematite suggested for magnetic ferric oxide or oxidized magnetite, as distinct from martite. *See* Oxymagnite. [M.A. **4**–215.]

T. L. Walker (Univ. Toronto Studies, Geol. Ser., 1930, no. 29, p. 19) applies this name to a magnetic and anisotropic mineral consisting of mixed sesquioxides of iron and titanium, $(Fe,Ti)_2O_3$, from the Bushveld, Transvaal. [M.A. **4**–348.]

Magnesiohastingsite. M. Billings, 1928. *See* Ferrohastingsite.

Maitlandite. E. S. Simpson, 1930. Journ. Roy. Soc. W. Australia, vol. 16, p. 33. Hydrous silicate of thorium, uranium (UO_2), &c., $2(Pb,Ca)O.3ThO_2.4UO_2.8SiO_2.23H_2O$, differing from mackintoshite (to which the mineral had been provisionally referred in 1912) in containing some lead and calcium. Named after Andrew Gibb Maitland, formerly Government Geologist of Western Australia. [M.A. **4**–346.]

Mangandiaspore. K. Chudoba, 1929. Centr. Min., Abt. A, 1929, p. 11 (Mangandiaspor). A variety of diaspore containing some manganese (Mn_2O_3 4·32 %) from South Africa. [M.A. **4**–148.]

Manganese-pennine. G. Aminoff, 1931. H. Eckermann, Geol. För. Förh. Stockholm, 1927, vol. 49, p. 450 (manganese-chlorite). G. Aminoff, Kungl. Svenska Vetenskapsakad. Handl., 1931, ser. 3, vol. 9, no. 5, p. 13 (manganese-pennine). A variety of pennine containing MnO 1 %, from Långban, Sweden. [M.A. **3**–474; **4**–469.]

Manganilmenite. E. S. Simpson, 1929. Journ. Roy. Soc. W. Australia, vol. 15, p. 103. A variety of ilmenite containing MnO 14·40 %, from Western Australia. [M.A. **4**–315.]

Maufite. F. E. Keep, 1930. Trans. Geol. Soc. S. Africa, vol. 32 (for 1929), p. 103; Bull. Geol. Survey Southern Rhodesia, 1930, no. 16, pp. 26, 33. Hydrous silicate of aluminium, magnesium, and nickel (NiO 4·28 %), $(Mg,Fe,Ni)O.2Al_2O_3.3SiO_2.4H_2O$, forming fibrous emerald-green veins in serpentine from Southern Rhodesia. Named after Herbert Brantwood Maufe, Director of the Geological Survey of Southern Rhodesia. [M.A. **4**–248, 413.]

Metamesolite. A. Cavinato, 1927. Mem. R. Accad. Lincei, Cl. Sci. fis. mat. nat. Roma, ser. 6, vol. 2, p. 339. Artificially dehy-

drated mesolite showing a change in the optical characters. Analogous to the metascolecite, &c., of F. Rinne. [M.A. **4**–321.]

Millisite. E. S. Larsen and E. V. Shannon, 1930. Amer. Min., vol. 15, p. 329. Hydrous phosphate of calcium, sodium, and aluminium, $2CaO.Na_2O.6Al_2O_3.4P_2O_5.17H_2O$, as white crusts (monoclinic?) in variscite nodules from Utah. Named after Mr. F. T. Millis, of Lehi, Utah. [M.A. **4**–344.]

Montasite. (A. L. Hall, Mem. Geol. Survey South Africa, 1930, no. 12 (2nd edit.), pp. 27, 40.) Trade-name for a fine quality fibre asbestos from the Montana mine, Pietersburg, Transvaal; identical with amosite, a variety of anthophyllite.

Mooreite. L. H. Bauer and H. Berman, 1929. Amer. Min., vol. 14, pp. 103, 165. Hydrous basic sulphate of magnesium, zinc, and manganese, $7R(OH)_2.RSO_4.4H_2O$ (for δ-mooreite, $6R(OH)_2.RSO_4.4H_2O$), as tabular monoclinic crystals from New Jersey. Named after Gideon Emmet Moore (1842–1895), mineral chemist of New York City. [M.A. **4**–151.]

Mourmanite. N. N. Gutkova, Dokl. Akad. Nauk SSSR (Compt. Rend. Acad. Sci. URSS), Ser. A, 1930, p. 730 (мурманит, mourmanite). French spelling of murmanite (A. E. Fersman, 1923; 10th List). Hydrated silico-titanate of sodium, &c. Named from the Murman Coast, Russian Lapland.

Nagatelite. S. Iimori, J. Yoshimura, and S. Hata, 1931. Sci. Papers Inst. Physical and Chemical Research, Tokyo, vol. 15, p. 87; Chem. News, London, 1931, vol. 142, p. 211. Hydrous phosphosilicate of cerium earths, aluminium, iron, and calcium, $4R^{II}O.3R^{III}_2O_3.6(SiO_2,P_2O_5).2H_2O$, as black monoclinic prisms, belonging to the epidote group and close to allanite. Named from the locality, Nagatejima, Ishikawa, Japan. [M.A. **4**–500.]

Nahcolite. F. A. Bannister, 1928. Nature, London, vol. 122, p. 866; Min. Mag., 1929, vol. 22, p. 60. Sodium bicarbonate, as minute [monoclinic] crystals in a mixture of salts found in a Roman conduit near Naples. Named from the chemical formula $NaHCO_3$ and λίθος, stone.

Nicolayite. E. S. Simpson, 1930. Journ. Roy. Soc. W. Australia, vol. 16, p. 33. Hydrous silicate of thorium, uranium (UO_3), &c.,

$2(Pb,Ca)O.3ThO_2.4UO_3.8SiO_2.21H_2O$, differing from thorogummite (to which the mineral had been provisionally referred in 1912) in containing some lead and calcium. Named after the late Rev. Charles G. Nicolay, who formed the first collection of Western Australian minerals. [M.A. **4**–346.]

Nuolaite. L. Lokka, 1928. Bull. Comm. Géol. Finlande, no. 82, p. 21 (Nuolait). A black mineral resembling wiikite but consisting of an intimate intergrowth of an opaque crystalline material and a colourless isotropic material. The bulk analysis indicates a hydrous meta-niobate (and tantalate) and titanate of yttrium, iron, thorium, &c. Named from the locality, Nuolainniemi, Impilahti parish, Lake Ladoga, Finland. [M.A. **4**–250.]

Oxymagnite. A. N. Winchell, 1931. Amer. Min., vol. 16, p. 270. A contraction of oxidized magnetite, to replace the name maghemite (q.v.) for magnetic ferric oxide. [M.A. **4**–502.]

Potash-margarite. F. C. Phillips, 1931. Min. Mag., vol. 22, p. 485. Synonym of lesleyite, for a margarite in which calcium is largely replaced by potassium.

Probertite. A. S. Eakle, 1929. Amer. Min., vol. 14, p. 427. Hydrous borate of sodium and calcium, '$Na_2CaB_6O_{11}.6H_2O$', as rosettes of monoclinic prisms embedded in kernite from California. Named after Prof. Frank Holman Probert, Dean of the Mining College, University of California. Identical with Kramerite (q.v.). [M.A. **4**–245.]

Pseudo-sarcolite. C. E. Tilley, 1929. Geol. Mag. London, vol. 66, pp. 349, 353 (pseudo-sarcolite), pp. 349, 352 (pseudosarcolite). The artificial product $3(Ca,Na_2)O.Al_2O_3.3SiO_2$, tetragonal and optically negative, prepared by A. F. Buddington (1922), differing from sarcolite in its optical properties. It is regarded as one of the constituent molecules of the minerals of the melilite group. [M.A. **4**–218; Min. Mag. **22**–463.]

Ramdohrite. F. Ahlfeld, 1930. Centr. Min., Abt. A, 1930, p. 365 (Ramdohrit). Sulphantimonite of lead and silver, $Ag_2S.3PbS.3Sb_2S_3$, as grey-black prisms from Bolivia. Named after Prof. Paul Ramdohr, of Aachen. [M.A. **4**–341.]

Rasorite. L. A. Palmer, 1927. Engin. & Mining Journ. New York, vol. 123, p. 494, 1928, vol. 125, p. 207; H. S. Gale, ibid., 1928, vol. 125, p. 702. The Mineral Industry, New York and London, 1927, vol. 35 (for 1926), p. 91. E. H. Kraus and W. F. Hunt, Mineralogy, 2nd edit., 1928, pp. 303, 380. Synonym of kernite (11th List). Named after Mr. Clarence M. Rasor, field engineer to the Pacific Coast Borax Company. [M.A. **4**–244.]

Renardite. A. Schoep, 1928. Bull. Soc. Franç. Min., vol. 51, p. 247 (renardite); Ann. Musée Congo Belge, Ser. I, Minéralogie, Tervueren (Belgique), 1930, vol. 1, fasc. 2, p. 34. Hydrous phosphate of uranium and lead, $PbO.4UO_3.P_2O_5.9H_2O$, as yellow orthorhombic crystals from Katanga. Named after Prof. Alphonse François Renard (1842–1903) of Gand (= Gent). [M.A. **4**–15, 313.]

Sanidine-anorthoclase. K. Chudoba, 1930. Centr. Min., Abt. A, 1930, p. 145 (Sanidinanorthoklas), p. 150 (Sanidin-Anorthoklas, Anorthoklas-Sanidin). Felspar from the Drachenfels, Rhine, with the tabular habit of sanidine but with the optical extinction of anorthoclase. [M.A. **4**–389.]

Scawtite. C. E. Tilley, 1929. Nature, London, vol. 124, p. 896. Min. Mag., 1930, vol. 22, p. 222; 1931, vol. 22, p. 457. Silicate and carbonate of calcium, $6CaO.4SiO_2.3CO_2$ (or perhaps $2CaCO_3.Ca_2Si_3O_8$), as minute monoclinic crystals in vesicles at the contact of chalk and dolerite at Scawt Hill, near Larne in Co. Antrim. Named from the locality.

Schairerite. W. F. Foshag, 1931. Amer. Min., vol. 16, p. 133. Sulphate and fluoride of sodium, $Na_2SO_4.Na(F,Cl)$, as colourless rhombohedral crystals from Searles Lake, California. Named after Dr. John Frank Schairer, of the Geophysical Laboratory, Washington. [M.A. **4**–498.]

Seamanite. E. H. Kraus, W. A. Seaman, and C. B. Slawson, 1930. Amer. Min., vol. 15, p. 220. Hydrous phospho-borate of manganese, $3MnO.(B_2O_3,P_2O_5).3H_2O$, as pale-yellow orthorhombic needles from Michigan. Named after Prof. Arthur E. Seaman, of the Michigan College of Mining and Technology. [M.A. **4**–342.]

Selenolinnaeite. V. Cuvelier, 1929. Natuurwetenschappelijk Tijdschrift, Antwerpen, vol. 11, p. 176 (Selenolinneïet). A seleniferous variety of linnaeite from Katanga. [M.A. **3**–362, **4**–248.]

Serandite. A. Lacroix, 1931. Compt. Rend. Acad. Sci. Paris, vol. 192, pp. 189, 193, 1324 (sérandite). Acid metasilicate of manganese, calcium, and sodium, $(Mn,Ca)_{7\cdot5}Na_3H_2(SiO_3)_{10}$, as peach-blossom-red monoclinic crystals in sodalite-syenite from the Los Islands, West Africa. Named after Mr. J. M. Sérand, a local collector. [M.A. **4**–497.]

Silicoilmenite. P. P. Pilipenko, 1930. Mineralnoe Syre, Moskva, 1930, vol. 5, p. 981 (Силикоильменит). A red-brown mineral intergrown with ilmenite from the Ilmen Mts., Ural, thought to represent a solid solution of silicate or silica in ilmenite. [M.A. **4**–499.]

Soda-dehrnite. E. S. Larsen and E. V. Shannon, 1930. *See* Dehrnite.

Soda-margarite. F. C. Phillips, 1931. Min. Mag., vol. 22, pp. 482, 485. Synonym of ephesite, for a margarite in which calcium is largely replaced by sodium.

Soda-melilite. H. Berman, 1929. Amer. Min., vol. 14, p. 398 (soda-melilite), pp. 400, 405 (soda melilite). A hypothetical molecule $Na_2Si_3O_7$ which is regarded as an end-member of the melilite group. Similarly, sub-melilite is $CaSi_3O_7$. [M.A. **4**–204.]

Stainierite. V. Cuvelier, 1929. Natuurwetenschappelijk Tijdschrift, Antwerpen, vol. 11, p. 177 (Stainieriet). A. Schoep and V. Cuvelier, Bull. Soc. Belge Géol. Pal. Hydrol., 1930, vol. 39 (for 1929), p. 74. W. F. de Jong, Natuurwet. Tijds., 1930, vol. 12, p. 69. A. Schoep, Ann. Service Mines, Katanga, 1930, vol. 1, p. 55. Hydrous sesquioxide of cobalt with some iron and aluminium, $(Co,Fe,Al)_2O_3.H_2O$, regarded as the crystalline equivalent of the colloidal heterogenite. From Katanga, Belgian Congo. Named after Xavier Stainier, Professor of Geology in the University of Gent (= Gand). [M.A. **4**–248, 347, 501.]

Stibiopalladinite. P. A. Wagner, 1929. The platinum deposits and mines of South Africa, Edinburgh & London, 1929, pp. 12, 15, 18, 227, 237. H. Schneiderhöhn, Centr. Min., Abt. A, 1929, p. 193; Chem. Erde, 1929, vol. 4, pp. 268, 275. Palladium antimonide, Pd_3Sb, as minute white grains (cubic ?) in the platiniferous norite of the Bushveld, Transvaal. First described as 'a new palladium mineral' by H. R. Adam, Journ. Chem. Metall. Mining Soc. South

Africa, 1927, vol. 27, p. 249, and later named from the chemical composition. [M.A. **3**–369 ; **4**–145, 149.]

Sturtite. T. Hodge-Smith, 1930. Rec. Australian Museum, vol. 17, p. 410. Hydrous silicate of manganous oxide and ferric oxide, $H_3FeMn_3Si_4O_{14}.10H_2O$, as amorphous jet-black masses from Broken Hill, New South Wales. Named after Captain Charles Sturt (1795–1869), who visited the locality in 1844. [M.A. **4**–345.]

Sub-melilite. H. Berman, 1929. *See* Soda-melilite.

Takizolite. S. Iimori and J. Yoshimura, 1929. Bull. Chem. Soc. Japan, vol. 4, p. 2 ; Sci. Papers Inst. Physical & Chemical Research, Tokyo, vol. 10, p. 225. A pink clay from Tanokami, Japan, intermediate in composition, $2Al_2O_3.7SiO_2.7H_2O$, between catlinite and montmorillonite. Named after the late Takizo Ueno, of Tanokami, who collected the material. [M.A. **4**–247.]

Tanteuxenite. E. S. Simpson, 1928. Journ. Roy. Soc. Western Australia, vol. 14, p. 45 ; Amer. Min., 1928, vol. 13, p. 467. Titanotantalate of yttrium, &c., $YtTi_2TaO_8$, differing from euxenite in containing tantalum in place of niobium ; as tabular orthorhombic crystals from Western Australia. [M.A. **4**–9, 184.]

Teepleite. (C. Doelter, Handbuch d. Mineralchemie, 1927, vol. 4, pt. 2, p. 663 ; Teepleit). Synonym of burkeite and gauslinite (11th List), described by J. E. Teeple in 1921.

Thucholite. H. V. Ellsworth, 1928 (see 11th List). Amer. Min., vol. 13, pp. 419, 438 (thū′-chō-lite). H. S. Spence, Amer. Min., 1930, vol. 15, p. 499. A. Faessler, Centr. Min., Abt. A, 1931, p. 10 (Thucholith). A brittle jet-black carbonaceous material with variable amount of ash which contains thorium, uranium, &c. It occurs as small nodules intimately associated with uraninite in pegmatite in Canada. Named from the chemical symbols of its chief components, Th, U, C, H, O, and *λίθος*, stone. [M.A. **4**–11, 502.]

Tsilaisite. W. Kunitz, 1929. Chemie der Erde, vol. 4, p. 225 (Tsilaisit). A hypothetical molecule, $H_8Na_2Mn_6Al_{12}Si_{12}B_6O_{62}$, of the tourmaline group, to explain the composition of a manganiferous tourmaline (MnO about 6 %) from Tsilaisina (Tsilaizina), Madagascar. Named from the locality. [M.A. **4**–204.]

Ugandite. E. J. Wayland and L. J. Spencer, 1929. Min. Mag., vol. 22, pp. 186, 187. Synonym of bismutotantalite, from Uganda.

Uvite. W. Kunitz, 1929. Chemie der Erde, vol. 4, p. 221 (Uvit). A hypothetical molecule, $H_8Ca_2Mg_8Al_{10}Si_{12}B_6O_{62}$, of the tourmaline group, to explain the composition of magnesia-lime-tourmaline (CaO 5·35 %) from province Uva, Ceylon. Named from the locality. [M.A. **4**–204.]

Vanadine. — Adam, 1869. Ann. Mines, Paris, ser. 6, Mém. vol. 15, p. 488; Tableau Minéralogique, Paris, 1869, p. 33. Synonym of vanadic ochre (J. D. Dana, 1868) = vanadic acid (J. E. Teschemacher, 1851). The existence of this as a mineral has been questioned by W. T. Schaller, Amer. Journ. Sci., 1915, ser. 4, vol. 39, p. 404 [M.A. **1**–262]. Cf. Alaite, 5th List.

Wischnewite. D. S. Belyankin, 1931. Centr. Min., Abt. A, 1931, p. 196 (Wischnewit). To replace the name sulphate-cancrinite or sulphatic cancrinite (E. S. Larsen and G. Steiger, 1916; 8th List) for $3Na_2Al_2Si_2O_8.Na_2SO_4.3H_2O$, of the davyne-cancrinite group. Named from the locality, Wischnewy Gory [Vishnevy Mts.], southern Ural. [M.A. **4**–499.]

Zamboninite. F. Stella Starrabba, 1930. Boll. Soc. Geol. Italiana, vol. 48 (for 1929), p. 259. Fluoride of magnesium and calcium. $CaF_2.2MgF_2$, as white radially fibrous masses from Etna, Sicily. Named after Professor Ferruccio Zambonini, of Napoli. The alternative name zambonina (= zambonine) is mentioned, but not adopted. Not the zamboninite of M. Bauer (1901, 6th List). [M.A. **4**–249.]

Zinc-manganese-cummingtonite. L. H. Bauer and H. Berman, 1930. Amer. Min., vol. 15, p. 341. An amphibole containing ZnO 10·46, MnO 13·79 %, as green prisms from Franklin Furnace, New Jersey. [M.A. **4**–345.]

Zirklerite. E. Harbort, 1928. Kali, Halle, vol. 22, p. 157 (Zirklerit). Hydrous chloride of ferrous iron, magnesium, and calcium with aluminium hydroxide, $9\{(Fe,Mg,Ca)Cl_2.2H_2O\} + 2\{Al_2O_3.H_2O\}$, rhombohedral; from the north German potash-salt deposits. Named after Bergrat Dr. — Zirkler, Director of the Aschersleben potash works. [M.A. **4**–14.]

SYSTEMATIC CLASSIFICATION OF NEW MINERALS.[1]

Sulphides, &c.

Stibiopalladinite, Pd_3Sb.
Cooperite, PtS_2.
Gudmundite, FeSbS.
Antamokite, Au telluride.
Selenolinnaeite, var. of linnaeite.

Sulpho-salts.

Fülöppite, $2PbS.3Sb_2S_3$.
Ramdohrite, $Ag_2S.3PbS.3Sb_2S_3$.

Haloids.

Zamboninite, $CaF_2.2MgF_2$.
Haematophanite, $Pb(Cl,OH)_2.4PbO.2Fe_2O_3$.
Zirklerite, $9\{(Fe,Mg,Ca)Cl_2.2H_2O\} + 2\{Al_2O_3.H_2O\}$.

Oxides.

Maghemite, magnetic $(Fe,Ti)_2O_3$.
Manganilmenite, var. of ilmenite.

Hydroxides.

Bayerite, $Al(OH)_3$.
Mangandiaspore, var. of diaspore.
Stainierite, $(Co,Fe,Al)_2O_3.H_2O$.

Carbonates.

Nahcolite, $NaHCO_3$.
Cobaltsmithsonite, $(Zn,Co)CO_3$.
Loseyite, $2(Mn,Zn)CO_3.5(Mn,Zn)(OH)_2$.

Sulphates.

Schairerite, $Na_2SO_4.Na(F,Cl)$.
Krausite, $K_2SO_4.Fe_2(SO_4)_3.2H_2O$.
Klebelsbergite, basic sulph. Sb.
Bianchite, $FeZn_2(SO_4)_3.18H_2O$.
Mooreite, $7R(OH)_2.RSO_4.4H_2O$; [R = Mg,Zn,Mn].

Uranate.

Clarkeite, $(Na_2,Pb)O.3UO_3.3H_2O$.

Borates.

Ammonioborite, $(NH_4)_2O.5B_2O_3.5H_2O$.
Probertite, $NaCaB_5O_9.5H_2O$.
Seamanite, $3MnO.(B_2O_3,P_2O_5).3H_2O$.

Phosphates, Arsenates, &c.

Collieite, Ca -V- pyromorphite.
Bialite, hyd. phosp. Al,Mg,Ca.
Arsenoklasite, $Mn_3(AsO_4)_2.2Mn(OH)_2$.
Fervanite, $2Fe_2O_3.2V_2O_5.5H_2O$.
Renardite, $PbO.4UO_3.P_2O_5.9H_2O$.
Dehrnite, $7CaO.Na_2O.2P_2O_5.H_2O$.
Deltaite, $8CaO.5Al_2O_3.4P_2O_5.14H_2O$.
Dennisonite, $6CaO.Al_2O_3.2P_2O_5.5H_2O$.
Lewistonite, $15CaO.(K,Na)_2O.4P_2O_5.8H_2O$.
Englishite, $4CaO.K_2O.4Al_2O_3.4P_2O_5.14H_2O$.
Millisite, $2CaO.Na_2O.6Al_2O_3.4P_2O_5.17H_2O$.
Lehiite, $5CaO.(Na,K)_2O.4Al_2O_3.4P_2O_5.12H_2O$.
Gordonite, $MgO.Al_2O_3.P_2O_5.9H_2O$.
Landesite, $3Fe_2O_3.20MnO.8P_2O_5.27H_2O$.

Silico-arsenite.

Allodelphite, $5MnO.2Mn_2O_3.As_2O_3.SiO_2.5H_2O$.

Niobates, Tantalates.

Bismutotantalite, $BiTaO_4$.
Calciotantalite, var. of tantalite.
Tanteuxenite, $YtTi_2TaO_8$.
Nuolaite.

Silicates.

Achromaite, var. of hornblende.
Alkali-hastingsite, ,,
Ferrohastingsite, ,,
Magnesiohastingsite, ,,
Lithium-amphibole, ,,
Zn-Mn-cummingtonite, ,,

[1] Only a selection of the names given in the preceding alphabetical list is here included.

Alkali-beryl, var. of beryl.
Caesium-beryl, ,,
Beryllium-vesuvianite.
Buszite, sil. rare-earths.
Lessingite, $H_2Ca_2Ce_4Si_3O_{15}$.
Larnite, Ca_2SiO_4.
Scawtite, $6CaO.4SiO_2.3CO_2$.
Nagatelite,
$4R^{II}O.3R^{III}{}_2O_3.6(SiO_2,P_2O_5).2H_2O$;
[R^{II} = Fe,Ca; R^{III} = Al,Ce,La,Yt].
Arandisite, $3SnSiO_4.2SnO_2.4H_2O$.
Serandite, $(Mn,Ca)_{7\frac{1}{2}}Na_3H_2(SiO_3)_{10}$.
Ameletite,
$9Na_2O.6Al_2O_3.12SiO_2.\frac{1}{2}NaCl$.
Fersmanite, $4(Ca,Na_2)TiO_3$.
$2(Ca,Na_2)_2Si(O,F)_3.SiO_2$.
Murmanite, hyd. sil. tit. Na.
Dickite, $Al_2O_3.2SiO_2.2H_2O$.
Takizolite, $2Al_2O_3.7SiO_2.7H_2O$.
Kanbaraite, $H_4Al_2MgSi_6O_{18}.xH_2O$.
Elbrussite, hyd. sil. Al,Fe,Mg,Alk.
Maufite,
$(Mg,Fe,Ni)O.2Al_2O_3.3SiO_2.4H_2O$.
Sturtite, $H_3FeMn_3Si_4O_{14}.10H_2O$.
Maitlandite,
$2(Pb,Ca)O.3ThO_2.4UO_2.8SiO_2.23H_2O$.
Nicolayite,
$2(Pb,Ca)O.3ThO_2.4UO_3.8SiO_2.21H_2O$.
Wischnewite,
$3Na_2Al_2Si_2O_8.Na_2SO_4.3H_2O$.

HYDROCARBONS.

Almashite, var. of amber.
Thucholite.

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